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SMUD OFF-PEAK OVER-COOLING PROJECT

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PREFACE

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ABSTRACT

California's summer peak electrical demand continues to grow despite strict building and appliance standards and utility programs promoting energy efficiency options. The Sacramento Municipal Utility District is a summer peaking utility with a system strongly driven by residential and commercial air conditioning. In this project, the Sacramento Municipal Utility District was investigating the feasibility of off-peak residential pre-cooling as way to control peak demand growth. This study assessed current control capabilities in the demand response field, completed computer modeling to assess potential benefits, field-tested promising pre-cooling strategies, and evaluated the compatibility of pre-cooling strategies with the generation profile of a wind generation facility owned by the Sacramento Municipal Utility District.

Project results indicated that combining air conditioner pre-cooling with energy efficient night ventilation cooling in the Sacramento climate could reduce full cooling season energy consumption by 88 percent during the Sacramento Municipal Utility District's 5:00 to 8:00 p.m. super-peak period. This result was highly encouraging, although it was based on limited field-testing and computer modeling. A further, broader study is warranted to validate these results. Implementing this strategy in the Sacramento Municipal Utility District's new highly energy efficient SolarSmart homes program would be an effective test of the advanced pre-cooling option. If viable, this strategy could provide near-term benefits to the Sacramento Municipal Utility District until more advanced one- or two-way utility-to-home communication strategies become viable.

Keywords: Pre-cooling, efficient building envelopes, residential, load-shift, comfort, demand reduction

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EXECUTIVE SUMMARY

Introduction

Pre-cooling building mass can be an effective strategy for eliminating or reducing on-peak air conditioner operation. Night cooling was often the only strategy to achieve moderate comfort levels in homes before the widespread use of vapor compression air conditioning. Increased saturation of air conditioning, more discriminating homeowner comfort preferences, and global climate impacts have resulted in less use of pre-cooling strategies and a rise in peak electrical demand for many California utilities in the past 30 years. Contractors build new homes with improved cooling load reduction measures and higher quality thermal envelopes, increasing the likelihood that building cooling stored during non-peak times can be retained during the peak period. Night ventilation pre-cooling can effectively complement air conditioner pre-cooling as a combined strategy for shifting residential cooling demand from on-peak to off-peak periods. This is especially true in the Sacramento climate, where summer nights are characterized by cool temperatures. Next day on-peak cooling loads can be significantly reduced or eliminated by effectively ventilating and pre-cooling building mass overnight. When the critical utility peak period begins, the house would ideally coast through the peak period, depending upon the weather severity, thermal integrity of the building envelope, and length and timing of the peak period.

The concept of pre-cooling represents a potentially effective strategy for California summer peaking utilities by shifting demand to lower demand periods. The Sacramento Municipal Utility District (SMUD) is a summer peaking utility with its residential peak load strongly driven by cooling demand. SMUD's pilot residential Power Save Plus (PSP) rate features a weekday 5:00 to 8:00 p.m. super-peak period that coincides with the peak residential cooling demand and SMUD's highest energy costs. The SMUD Board of Directors developed a 10-year goal to reduce customer energy use and peak demand by 15 percent. This initiative spurred increased interest in new construction efficiency programs, photovoltaic incentives, pre-cooling, and other measures as potential strategies for minimizing new power plant construction needs and maximizing existing generation and transmission infrastructure use.

Project Purpose

The goal of this project was to research existing pre-cooling hardware options, complete field testing of a preferred cooling strategy, evaluate data, and report results. The primary objectives were:

- Identifying potential pre-cooling technologies and control options that would facilitate optimized pre-cooling operation.
- Analyzing available options and identifying a preferred pre-cooling strategy.
- Completing computer simulations of the preferred design to project its performance.
- Performing field monitoring of the preferred design to assess real world performance, operating characteristics, and suggested improvements.

- Evaluating potential synergies between SMUD's 102-megawatt (MW) Solano wind plant production profile and projected demand profiles for both conventional air conditioned homes and pre-cooled homes.
- Generating recommendations for future work based on project results and conclusions.

Project Results

Project results clearly indicated that a combined night ventilation and air conditioner pre-cooling strategy could be part of SMUD's broad package of solutions for meeting continued peak demand growth within its service territory. Specific key project outcomes included:

- The areas of demand response and programmable communicating thermostats were evolving quickly, and it is difficult to project where technology and the marketplace will go. Ideally, a preferred future strategy would be installing an electric meter to serve as the gateway for a utility to communicate with the HVAC thermostat and other high electrical demand appliances, as well as to provide timely feedback to homeowners. This communication could take the form of price signals as well as on/off control signals in the event of peak load emergencies.
- The NightBreeze night ventilation cooling system represented the best short-term solution for a cost-effective control and hardware package for providing ventilation and air conditioner pre-cooling. The current control operated effectively as a pre-cooling control, although some refinements were needed to minimize excessive air conditioner pre-cooling on mild days.
- Detailed hourly building models using the DOE2 simulation indicated a preferred air conditioner pre-cooling interval of five hours prior to the SMUD 5:00 to 8:00 p.m. super-peak would provide the best homeowner economics and greatest utility benefit. DOE2 projections for the typical house modeled suggested energy savings of 440 kilowatts (kWh) per year (24 percent) with the combined NightBreeze plus air conditioner pre-cooling strategy. The research team estimated a super-peak cooling energy savings of 97 percent and operating cost savings of $111 (21 percent) under the pilot SMUD Power Save Plus rate.
- Field monitoring of air conditioner and ventilation cooling plus air conditioner pre-cooling in 2006 was inconclusive due to a shortened monitoring period, variable weather conditions, and operational problems. Monitoring in 2007 was subsequently added to bolster the 2006 field monitoring results. In 2007, a NightBreeze equipped home located in Folsom (east of Sacramento) resulted in successful data collection for the full summer period. Performance results during 2007 suggested that the NightBreeze plus air conditioner pre-cooling strategy could effectively reduce full-season super-peak cooling energy consumption by an impressive 88 percent vs. base case, but that overall cooling energy usage could increase by 26 percent. The net impact on the homeowner's electric bill under the SMUD PSP pilot rate was an estimated $9 per year increase in cooling costs ($158 vs. $149). The 2007 results and projections were considered conservative

since the NightBreeze system was undersized for the field test house and the installed cooling system did not have sufficient capacity to provide pre-cooling on days when outdoor temperatures exceeded 100 degrees Farenheit. Although 2007 field results were not as positive as the original DOE2 projections in terms of total cooling energy use, the field results present a strong case for further field studies.

- Evaluation of wind generation data from a 102-MW SMUD Solano County wind farm suggested a good match with summer wind generation profiles since pre-cooling strategies utilized electrical energy when the wind resource is available and reduced consumption when the yield was low. The researchers' analysis estimated that a fleet of roughly 5000 to 10,000 homes with an air conditioner and ventilation pre-cooling system would be needed to offset the wind farm peak period shortfall.

The results from this study were promising enough to justify further efforts to better understand pre-cooling benefits on a statistically valid sample of SMUD customers. Specific activities to be considered include:

- Pursuing additional detailed field testing with SmartVent systems and NightBreeze systems (target airflow of 0.6 cubic feet per minute per square foot of floor area) coupled with conventionally sized, air-cooled air conditioners. The 2007 monitoring was beneficial, but the monitored home is atypical of new SMUD production housing.
- Completing energy use monitoring for cooling energy consumption on 30 to 50 new (high cooling performance) homes in both base case and ventilation cooling plus pre-cooling modes of operation. An ideal candidate for inclusion in that type of program would be SMUD SolarSmart home builders. These homes incorporate many of the cooling energy efficiency measures that are needed for a successful pre-cooling strategy.
- Working with ventilation cooling product vendors to enhance pre-cooling capabilities to minimize air conditioner over-cooling on milder days. Enhanced performance could be achieved by adding an indirect evaporative cooling module to the outside air intake of a SmartVent or NightBreeze ventilation cooling system, but this effort would require further product development.
- Combining the electrical load patterns observed in the 2007 monitoring study with SMUD hourly marginal cost data to determine if the load shifting benefits are fairly reflected in the SMUD PSP pilot rate.
- Surveying a broad sample of SMUD homeowners to determine comfort preferences, specifically what percentage could tolerate indoor temperature fluctuations of approximately 10 degrees Farenheit during the course of a day if they save "X" percent on their electric bill. An important part of assessing wide-scale pre-cooling acceptance would be understanding thermostat schedules, thermostat control patterns, and the level of incentives necessary to change behavior.

- Encouraging similar pre-cooling monitoring studies with other California utilities. Other utilities may have peak periods occurring earlier in the day, allowing for potentially greater efficiency advantages since air conditioner pre-cooling would occur earlier in the day.
- Collecting data from a statistically valid sample of homes in a broader pilot program to provide a better understanding of how the wind resource meshes with ventilation cooling/air conditioner pre-cooling.
- Supporting efforts to review and update standard hourly weather files used for DOE2 and other hourly simulation models to ensure heat storm events are properly included.

Project Benefits

The immediate benefit of residential pre-cooling is addressing statewide peak demand issues. Shifting peak load to shoulder or off-peak periods increases the reliability of the generation, transmission, and distribution infrastructure. Additionally, shedding peak load increases transmission efficiencies since transmission system peak losses are highest when system demand is highest. Reducing super peak demand would also reduce the state’s reliance on gas generation peaker units, resulting in beneficial air quality impacts. Improvements in night ventilation performance (or augmented night ventilation systems) coupled with improved control of air conditioner pre-cooling (avoiding unnecessary cooling) could eliminate the current cooling energy penalty of about 25 percent.

Monitoring results in 2007 suggested that SMUD achieved super-peak period energy savings of close to 90 percent when homeowners tolerated indoor temperatures up to 80 degrees Farenheit. Theoretically, demand savings approaching this level could be achieved if homeowner comfort was marginally compromised on the peak demand days. Alternatively, demand savings of approximately 50 percent are easily achievable without compromising indoor comfort by either cycling the air conditioner off for most of the super-peak period or operating a two-speed condensing unit only at low speed. A conservative 50 percent reduction would amount to demand savings of 1.5 kW per household based on the typical SMUD diversified residential cooling demand of 3 kW.

Chapter 1: Introduction

1.1 Background and Overview

The Sacramento Municipal Utility District (SMUD) serves 520,000 residential customers in the area surrounding Sacramento, California. SMUD's peak summer demand of roughly 3200 MW is strongly driven by residential and commercial air conditioning due to hot Central Valley summer weather conditions. Strong residential construction growth during the past five years has contributed to an increase in peak residential demand. SMUD is pursuing various avenues to control peak demand, including new construction energy efficiency programs geared toward managing cooling demand, incentives for photovoltaic system installation, and strategies for air conditioner pre-cooling.

The latter element is the focus of this study that evaluates the feasibility of utilizing air conditioner and night ventilation pre-cooling as a means of shifting load from on-peak to off-peak periods. Four key factors affect the viability of pre-cooling strategies:

The length of the on-peak period.

The ability to effectively pre-cool homes on hot days.

The ability of the home to retain the stored cooling during the peak period.

The availability of a favorable time-of-use electric rate structure that provides a sufficient rate differential to reward off-peak consumption and penalize on-peak consumption.

Night ventilation pre-cooling can be an effective part of an overall off-peak cooling strategy in climates such as Sacramento's by substituting low-energy ventilation cooling for more energy intensive compressor-based cooling. Next day on-peak cooling loads can be significantly reduced by effectively ventilating and pre-cooling building mass throughout the night. As outdoor (and indoor) temperatures begin to rise during the morning and midday hours, air conditioner operation can be triggered in response to a setpoint below the normal cooling setpoint. When the critical utility peak period begins, the house will ideally coast through the peak period, depending upon the weather severity, thermal integrity of the building envelope, and length of the peak period. A strategy such as this is likely best suited for energy efficient homes such as those being built under SMUD's SolarSmart homes program.1

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1. The SolarSmart homes program combines energy efficiency and photovoltaic systems to deliver high levels of energy efficiency (exceeding Title 24 by more than 35 percent). High quality thermal envelopes make these homes ideal candidates for an effective pre-cooling program. More information on the SolarSmart homes can be found at: http://www.solarpowerconference.com/news/news.php?id=41

1.2 Project Objectives

The primary objectives of the SMUD Off-peak Over-cooling Project are as follows:

1. Identify potential pre-cooling technologies and control options that would facilitate optimized pre-cooling operation.
2. Analyze the options and identify a preferred optimal package.
3. Complete computer simulations of the preferred design to estimate performance.
4. Perform field monitoring of the preferred design to assess real world performance, operating characteristics, and suggested improvements.
5. Evaluate potential synergies between SMUD's 102 MW Solano wind plant production profile with projected demand profiles for both conventional air conditioned homes and pre-cooled homes.
6. Generate recommendations for future work based on project results and conclusions.

1.3 Report Organization

This PIER final report reviews work completed to evaluate various pre-cooling methods and control and communications strategies appropriate for SMUD's residential customers. The project is comprised of six primary tasks:

- Task 1: Identify Technical Strategies for Evaluation
- Task 2: Select Optimum Control and HVAC packages
- Task 3: Design and Test Off-Peak Over-Cooling Systems
- Task 4: Field Monitoring of Over-Cooling Strategies
- Task 5: Evaluate Over-Cooling Suitability with Wind Generation
- Task 6: Reporting

This report summarizes work completed over the approximate three year term of the project describing the project approach (Section 1), technical pre-cooling strategies (Section 2), currently available pre-cooling methods and hardware (Section 3), emerging technologies (Section 4), development and testing of a stand-alone pre-cooling system; results of simulations and monitoring; and an assessment of the value of pre-cooling with respect to availability of the wind generation resource (Section 5).

1.4 Project Approach

The research team completed this project in several phases with different objectives. In the first two tasks, the project researched pre-cooling technology approaches. In the second task, the team developed a stand-alone pre-cooling control using the NightBreeze ventilation cooling control platform. DEG completed this work at the conclusion of a 2005 PIER project (Davis Energy Group, 2005) to add furnace control and zoning capability to the NightBreeze ventilation cooling system.

Concurrently, DEG coordinated with Michael Breton of Intel to monitor the performance of his house using a system of his design that included wireless communication between his house's electric meter and home computer system to allow home energy use to be displayed on a "My Energy" website. DEG prescribed a pre-cooling schedule for the house, but due to intermittent operation of the data acquisition system, this monitoring did not yield useful results. DEG also completed computer simulations of the Breton house to estimate the impact of pre-cooling.

Five houses were identified for a field monitoring study during 2006, with the intention of installing the NightBreeze ventilation cooling controls with pre-cooling functions.2 Due to delays in finalizing and debugging control firmware, controls were not available during the 2006 cooling season. Some useful monitoring data was obtained from those houses by applying scheduled thermostat settings.

Useful field test results were finally obtained during 2007 with the monitoring of a recently "energy doctored" home in SMUD territory. The homeowner installed a NightBreeze ventilation cooling/pre-cooling control on his new variable speed furnace, and the system was monitored in a variety of pre-cooling and standard operating modes. Methods and results are summarized for each of these phases.

Table 1 provides an annotated history of key project milestones during the two-and-a-half year project timeline.

Table 1: Project Timeline and Key Milestones

Date	Description
July 2005	Project start-up
August	Complete draft Technologies and Strategies report; coordinate activities with Intel staff on using a home PC-based system as part of an interface between the utility meter, the home thermostat, and the homeowner.
Sept/Oct	Install monitoring equipment in three Intel homes; monitor performance through last weeks of summer; finalize Technologies and Strategies report.
Winter 2005	Research communicating thermostats, wireless technologies, and control options.

2. The five selected houses were all SmartVent systems with variable speed furnaces. The availability of the NightBreeze gas furnace control system would have allowed the controls to be installed.

Date	Description
May 2006	Coordinate with new SMUD project manager; plan 2006 monitoring strategy.
July	Identify five field sites; secure monitoring agreements; procure monitoring equipment
Aug/Sept	Install and monitor five field sites; complete preliminary DOE2 computer modeling to identify 5° pre-cooling temperature reduction during a 1 to 5 p.m. period.
Nov/Dec	Complete field data analysis; deliver HVAC and Controls report.
Jan/Feb 2007	Deliver draft and final Field Monitoring report.
March	Deliver Wind Energy evaluation report.
April	Plan 2007 monitoring at single field site.
May	Install monitoring equipment at field site; complete additional DOE2 modeling identifying preferred pre-cooling strategy (5° pre-cooling temperature reduction during noon to 5 p.m. period); deliver Control Testing and Performance Assessment report.
June-Sept	Monitor field site.
Oct-Nov	Analyze field data; complete draft and final project report.

Chapter 2:
Pre-Cooling Strategies

2.1 Air Conditioner Pre-Cooling

Air conditioners are present in nearly all production homes in SMUD territory, and although they are often costly to operate, they provide a simple, direct means of pre-cooling. A mitigating feature of air conditioners is that their efficiency (defined as cooling delivered per unit of energy consumed3) improves at lower outdoor temperatures, so the penalty for operating compressors during morning hours is not as great as when they are operated on-peak. Typical units show a 25 percent improvement in Energy Efficiency Ratio (EER) when the outdoor temperature is 75°F compared to 100°F.

Air conditioners can be easily scheduled to cool building mass by simply programming a thermostat schedule that lowers the temperature during the morning hours and raises the setpoint in the afternoon. A DOE2 computer simulation evaluation of the potential peak load reduction for operating an air conditioner in this mode (Beutler 2003) showed a reduction of on-peak air conditioner use ranging from 75 to 84 percent (depending on house design and utility time-of-use period definition). Completed for houses in PG&E territory, the analysis applied PG&E's noon to 6 p.m. on-peak period and used a cooling setback to 72°F from 6 a.m. to noon, and a setup to 78°F the remainder of the day. SMUD's pilot Time of Use (TOU) schedule has a 5 to 8 p.m. super-peak period, requiring pre-cooling to occur during times approaching peak outdoor temperature (i.e. high cooling loads), effectively eliminating any benefit due to operating during cooler parts of the day.

An advantage of using the existing air conditioner for pre-cooling is that it can be accomplished at zero incremental cost, since the cooling equipment and setback thermostat are already present.

2.2 Ventilation Cooling

Ventilation cooling obtained by operating windows has been a common means of making homes more comfortable. This is especially true in the greater Sacramento climate where nighttime temperatures can easily be 35 to 40°F lower than daytime high temperatures. Increased market penetration of air conditioners and greater homeowner concerns about security, outdoor noise, and dust/pollen is decreasing window use, especially during the nighttime hours. Newer homes are also larger, which typically means more separate rooms with interior doors preventing effective cross-ventilation. Whole house fans have enjoyed some popularity, but require windows for effective operation. Beutler Corporation began producing

3. Energy Efficiency Ratio, or EER, represents the cooling delivered divided by the energy consumed by the air conditioning unit at a particular operating condition. EER is expressed in terms of Btu/Watt-hour.

the SmartVent central ventilation system in the 1990s.4 The system uses the furnace fan to introduce outdoor air in ventilation cooling mode (while exhausting indoor air to the attic), but operates like a conventional system during air conditioner and furnace operation. Figure 1 generically depicts the SmartVent/NightBreeze system configuration in each mode of operation.

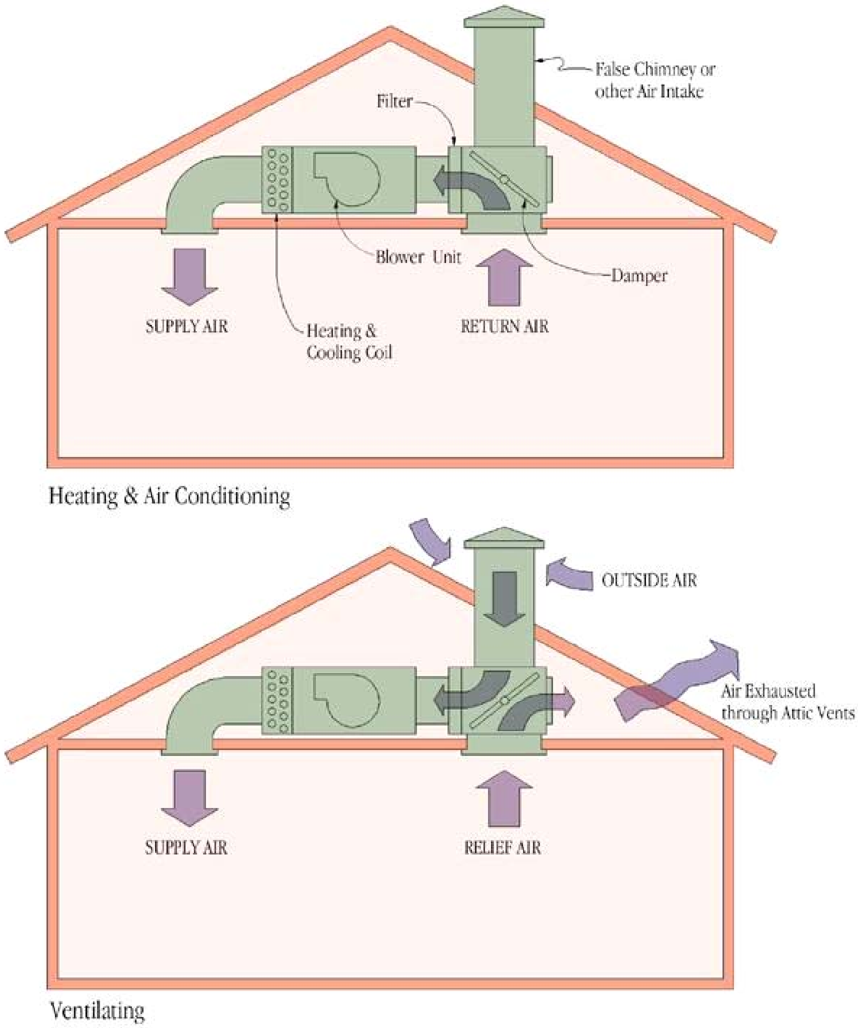

Figure 1: SmartVent/NightBreeze Operating Characteristics

Photo Credit: Buetler Corporation

In 1994, a comprehensive study to investigate the use of mechanical ventilation cooling as a means of reducing peak load was launched by the California Institute for Energy Efficiency with ongoing support from the California Energy Commission's Public Interest Energy Research Program (PIER). Called the Alternatives to Compressor Cooling project, the study concluded that when properly applied in a highly energy efficient home, mechanical ventilation

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4. Sales to date are close to 20,000 units.

cooling could reduce annual cooling energy use by 35 percent or more in the Central Valley, and reduce peak load by about 2 kW in Climate Zone 12 (Springer 2005).5

The NightBreeze system utilizes the low-speed efficiency benefits of brush-less permanent magnet motors,6 and a predictive function that varies ventilation rate with cooling demand, to reduce the off-peak energy required to operate the ventilation fan and to improve comfort. The incremental cost for the NightBreeze system coupled to a variable speed furnace is about $1,400. Installation cost varies by contractor, but total installed cost should not exceed $2,500. The cost of the SmartVent system is approximately half of the NightBreeze system. PG&E provides new construction incentives of $500 per unit for NightBreeze systems7 and $250 per unit for SmartVent systems.

Whereas the SmartVent system delivers a fixed volume of ventilation air and cools the house to a fixed low-limit temperature, the NightBreeze system varies the volume of ventilation air as well as the low limit temperature as a function of the amount of cooling needed. On hot days the system attempts to cool to a lower indoor temperature and delivers more air than on mild days, providing comfort better tailored to the weather patterns. Both systems are likely to require little or no maintenance compared to conventional systems, except that filters may need to be changed more frequently because of the larger volume of air delivered. A more detailed comparison of the two ventilation system types can be found in Appendix A.

2.3 Evaporative Cooling

Evaporative coolers deliver air at a temperature that is a function of the outdoor wet bulb temperature, which is typically about 30°F cooler than peak summer dry bulb temperatures and 5 to 10°F lower during typical nights. Direct evaporative coolers add moisture to the air in the cooling process. Indirect evaporative coolers lower the enthalpy8 of air supplied without adding moisture, but are limited to the extent in which they can lower the temperature. Some new multi-stage indirect evaporative coolers (e.g. the Coolerado9) are capable of providing air

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5. These results were based on field data and DOE2 full-year simulations. DOE2 weather files do not contain real world heat storm weather conditions resulting in a likely overestimation of demand reduction potential.

6. These variable speed motors can provide airflow at cfm/Watt efficiencies three to four times higher at low fan speeds than at full fan speed.

7. Incentive includes $250 for night ventilation cooling and $250 for the NightBreeze variable speed furnace fan.

8. Enthalpy is the sum of the internal energy plus the product of the pressure and volume.

9. http://www.coolerado.com/

close to the wet bulb temperature, but the technology is costly and not yet widely available on the market. Two-stage (indirect-direct) evaporative coolers are available from several manufacturers,10 including Adobe Air, Essick Air, and Speakman CRS, but market penetration is limited.

The advantage that evaporative coolers offer for pre-cooling purposes is that they operate at much greater efficiency than vapor compression cooling systems, and they can provide very cool air during the nighttime when outdoor wet bulb temperatures are low. The disadvantages are the system increases space requirements (especially if it is used in addition to conventional air conditioning), its operation increases indoor humidity, and its public perception affects market acceptability. Most evaporative coolers do not couple to setback thermostats, so their use for off-peak cooling would have to be manually controlled, or they would require control modifications.

The cost of evaporative coolers ranges widely, depending on product type (direct, indirect, or indirect-direct) and product quality. Maintenance requirements due to scaling and corrosion are also an issue, particularly with the lower cost units.

2.4 Other Pre-Cooling Strategies

Both ventilation cooling and air conditioning remove heat from building mass by convection over interior mass surfaces. Circulating cool water through building mass is a more effective means of exchanging heat, and allows deeper penetration into the mass, longer time constants, and improved likelihood of peak load reduction. This method has been employed in several commercial buildings and a few homes (Architectural Energy Corporation 2003), using chilled water produced using vapor compression, cooling towers, or roof-spray cooling systems. For residential applications this approach would require tubing embedded in the concrete floors or in mass walls. A Building America-sponsored study completed on four houses in Borrego Springs, California, evaluated the use of an evaporative condenser to cool water circulated through a concrete slab, and the use of a condensing unit to chill water piped through the floor. The evaporatively cooled system had the potential to produce more than 1 ton of cooling while wet bulb temperatures were in the mid-50s to low 60s. A 13 SEER air conditioner was used in another house to chilled water piped through the floor. This system had an EER about twice that of a nearly identical house with the same model of condensing unit, but heat absorbed from the ground made the chilled water system only slightly more efficient overall. If radiant heating were prevalent in production homes, this means of cooling would be much easier to implement, but there are few production builders using radiant heating.

10. http://www.adobeair.com/index.html; http://www.essickair.com/; and http://www.oasysairconditioner.com/

Chapter 3: Currently Available Pre-Cooling Controls

3.1 Thermostat Temperature Scheduling

The simplest, no-cost strategy for accomplishing pre-cooling with conventional air conditioners is to lower the thermostat setting during the hours preceding the on-peak period. Since Title 24 requires setback thermostats, the necessary controls are already in place. However, pre-cooling houses every day would waste cooling energy and could result in comfort complaints. Ensuring that customers would maintain settings is problematic; thermostat settings can be changed by unknowledgeable family members, or lost during power outages or battery failure. Many people prefer to use the override settings on their thermostats rather than relying on programmed schedules, thus making pre-cooling settings ineffective.

3.2 Thermostat Scheduling Using Intelligent Functions

Pre-cooling would occur on every summer day using a conventional programmable thermostat's scheduling capabilities, wasting air conditioner energy and creating discomfort. Effective local control would need a thermostat that can identify air conditioning-driven peak demand events and respond accordingly.

The NightBreeze system includes an outdoor temperature sensor that samples the previous day's indoor and outdoor temperatures and uses them in statistical equations to predict the weather for the next day. Predicted temperatures are used to determine a "target" low-limit temperature for house ventilation in order to avoid air conditioning operation and regulate fan speed (ventilation rate).

The project initially developed this control to provide pre-cooling using cool nighttime air only. In the final project phase (that coincided with the current SMUD Off-Peak Over-Cooling Project), however, it added functional capability that applies vapor compression cooling if ventilation cooling is insufficient to achieve the desired amount of pre-cooling. A "pre-cooling offset" temperature is used to establish a reduced air conditioner set point during a user-selected time period preceding the utility peak period. For example, if a vent target temperature of 68ºF is calculated based on temperature conditions and if control settings include a vent offset temperature of 5ºF and a 10 a.m. to 2 p.m. pre-cool schedule, the system will attempt to ventilate the house down to 68ºF. If the outdoor temperature is not sufficiently low to cool the house to the 68ºF target temperature, the control will lower the air conditioner thermostat setting to 73ºF (68ºF plus 5°F offset) between the hours of 10 a.m. and 2 p.m. On a mild day when the ventilation target temperature might be 70°F, the house would only be pre-cooled to 75°F between 10 a.m. and 2 p.m.

The team enhanced the control algorithms during the project to allow predicted temperatures to be used for operating the air conditioner to pre-cool the house if it was not adequately cooled by outside air ventilation. The development of this control function is further described in this report.

The NightBreeze control is a communicating device, but firmware is not currently designed to receive external signals. There are two ways to utilize external signals. The control could use weather forecast data to improve its predictive capabilities, and utility signals could be used to set the pre-cool temperature or other pre-cooling control parameters.

3.3 Remotely Controlled Thermostat Setback

A number of home automation system manufacturers produce communicating thermostats that can be accessed via an Internet connection or other gateway. Remote control of thermostat settings would ensure temperatures are modified only on days when electricity demand is expected to be high, and since these days coincide with hot weather it is less likely that customers would complain about comfort. This approach could either be used to set back the thermostat by a fixed amount over a defined period, or incorporate the predictive features of the prior strategy. For example, the utility could vary the extent of the temperature setback according to the predicted peak load for the day. This global approach would not be as responsive to differences in individual house behavior, but might provide better assurance of a peak load reduction result.

Although Internet access is widespread, it does not reach all SMUD customers. Other communication pathways may be needed to successfully implement a remotely controlled pre-cooling program. Potential pathways are described in Section 4.

Chapter 4:
Emerging Communications Strategies and Gateways

4.1 Gateway Options

The development of a functional system that enables utility access to thermostat settings must solve the problem of how the demand response signal is conveyed between the utility and the house, and from the house to the thermostat. Such a system must include:

- A thermostat with communicating capability
- A communications link from the thermostat to a communications gateway
- A communications link from the gateway to the utility

Communicating thermostats are not common, but are available, and a California initiative may soon make them more prevalent in the marketplace. Communications systems within the house that use hard wiring, power line carrier, and RF communications are also available from various vendors that can provide a link to the gateway.

Linking the utility to the gateway is more challenging. Internet connections are available in many, but not all, homes, are relatively inexpensive and reliable, and provide two-way communications that can provide feedback on system operation. However, the use of the home PC and Internet connection raises several issues, such as security and homeowner responsibility for maintaining the connection. Radio frequency and microwave signals transmitted using networked radios have been used in utility air conditioner cycling programs and in pilot programs to communicate between utility stations and home automation systems in residences. In fact, until the past few years, SMUD would use radio-controlled switches to “cycle” off air conditioning systems for 10 to 30 minutes per hour during summer heat storms for more than 100,000 residential customers. Some companies are developing products that use utility lines to carry signals. Perhaps the most promising approach is the Advanced Meter Infrastructure (AMI), a communicating meter that will soon be field-tested for use in demand response systems by California investor-owned utilities.

Interest in dynamic load control and real time pricing has spawned a number of companies to develop prototype hardware and firmware to facilitate either one-way or two-way communications with customers’ HVAC systems using pagers and Wide Area Networks. Figures 2 and 3 show two concepts for a communications network that enables remote thermostat control. Figure 2 diagrams a one-way system using either a telephone line or a VHF paging signal to trigger a change in thermostat settings or to disable certain appliances during peak demand events. Figure 3 shows a two-way communications gateway that utilizes an Internet connection.

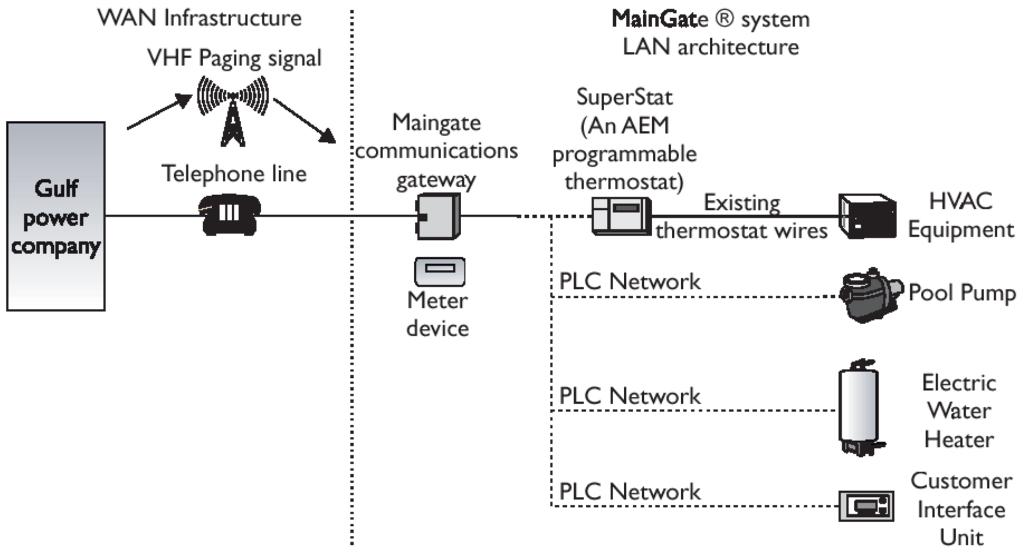

Figure 2: One-Way Communications Gateway

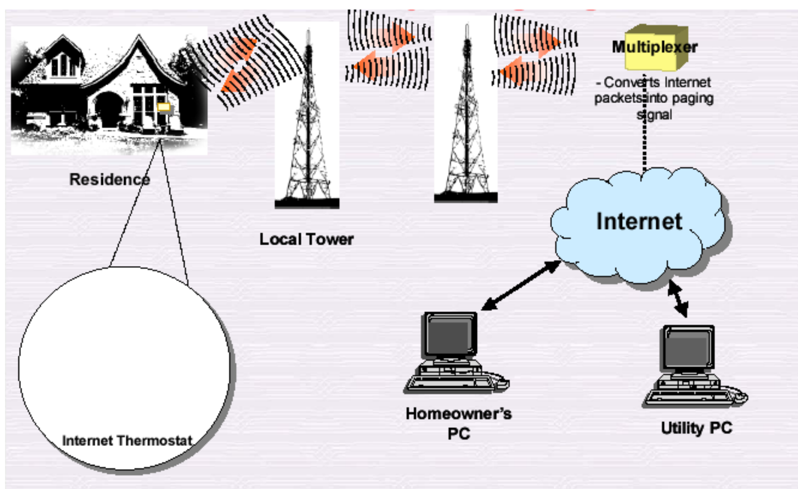

Figure 3: Two-Way Communications Gateway Using Internet Thermostat

Photo Credit: Buetler Corporation

Both of these systems utilize VHF paging to communicate with the thermostat. Providing a direct Ethernet connection to the thermostat is a lower-cost approach, but it would require homeowners to have broadband cable or DSL Internet connections. A system under development by RCS of Rancho Cordova, California, could provide this capability.

It would seem appropriate for communication systems to serve the multiple purposes of providing utility control of thermostat settings (and non-critical appliance loads), remote metering, real-time pricing, and energy use data to the homeowner. However, the quality and security requirements of utility meter data most likely dictates that meter data used for billing purposes should be kept separate from data used for other purposes.

4.2 Communicating Thermostats

4.2.1 California Energy Commission PCT Initiative

Recently there has been significant activity in California that will affect the future of demand response communications and control. The California Energy Commission proposed in its 2008 Title 24 Standards Rulemaking that all thermostats sold after a determined date be both programmable and communicating. The Commission held three workshops during 2005 and 2006 in an effort to encourage development of industry standards for these Programmable Communicating Thermostats (PCTs). The Commission's PCT initiative has the following objectives:

Implement a statewide PCT systems integration interface that is self-configuring and owner installed and maintained.

Create a PCT system that uses common signaling throughout state, works with any minimum AMI system, and is compatible with legacy technologies.

While the strategy behind the Commission's demand response efforts is to raise thermostat setpoints, the same infrastructure would be able to initiate pre-cooling by setting temperatures back during a demand response event. As of July 2006, the investor-owned utilities and the Commission have reached an agreement on the following key points:

- Pre-cooling response to emergency signals would reduce setpoint by 4°F, which cannot be overridden by a user.
- Pre-cooling response to price signals would reduce setpoint by 4°F, which can be overridden by user.
- External ports capable of receiving external modules could enable various communication modes and other features.
- Common user interface (LCD, LED) to provide information to a user, such as the type of demand response event and the status of the device.
- Standardized equipment connector for ease of installation and to minimize installation errors.

A diagrammatic concept of PCT controls and communications is shown in Figure 4.

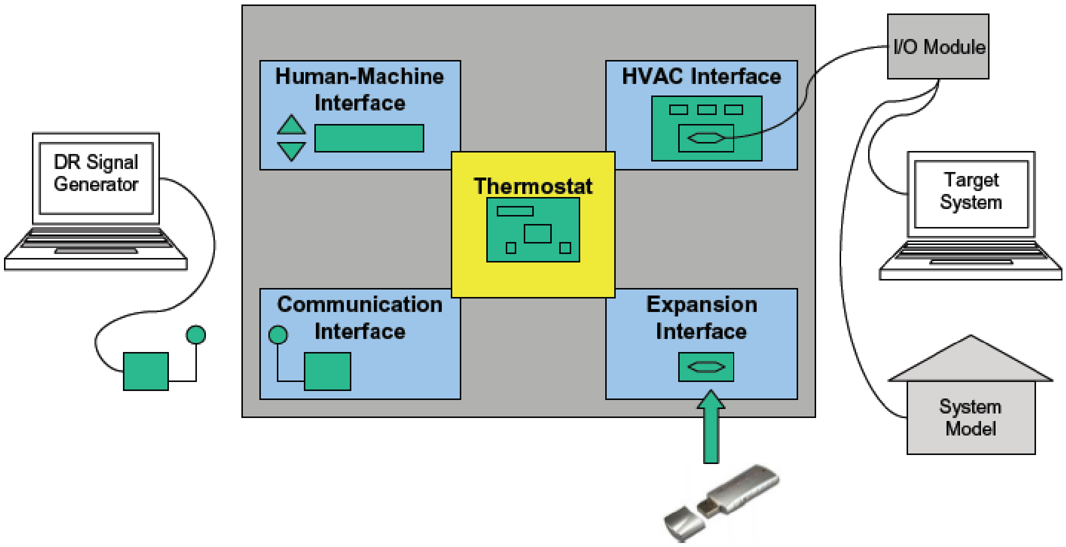

Figure 4: Diagrammatic Concept of DR System11

Photo Credit: Davis Energy Group

Protocols and standards for these thermostats are still being resolved with manufacturers. The Commission is contracting with University of California, Berkeley (Contract No. 500-01-043) to nurture this process. UC Berkeley's project objectives are to develop micro-electromechanical sensors and actuators; open-system, mesh-architecture communication systems that can seamlessly share data; real-time distributed intelligence device networks that are self-organizing; and enterprise-wide multilevel control strategies that can absorb legacy systems.

4.2.2 Industry Initiatives

Several manufacturers, such as Home Automated Living and AprilAire,12 currently offer communicating thermostats that allow homeowners to monitor temperatures and change thermostat settings as well as manage lighting, appliances, and other devices in their home from a remote location using Internet access. Possible future software extensions could support pre-cooling and or other energy management scenarios such as on-demand load shedding or whole house and end use metering. Work completed by Intel under this project, described in Section 4.3.2, also demonstrates the potential for web-based communications used to control special communicating thermostats.

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11. From presentation by Mazi Shirakh, California Energy Commission, July 12, 2006.

12. www.aprilaire.com

4.3 Communicating Meters

4.3.1 AMI Meters

Several utilities, including all California investor-owned utilities and SMUD, are in the process of implementing Advanced Meter Infrastructure (AMI) programs to deploy meters that can be remotely read by the utility, and that can potentially be used as communication gateways to thermostats and other systems in the house. Utilities see this as an opportunity to implement load control as well as automated meter reading using two-way communication. These two-way systems are still under development but may be deployed in 2008.

The enabling technology that will allow utilities to issue demand response signals to customers' thermostats using AMI meters or other avenues as gateways to individual HVAC system thermostats may be on the horizon. At the current time there is no infrastructure in place to allow the use of a utility signal to modify thermostat settings (as opposed to the simpler air conditioner cycling control). The only current alternative to utility initiated demand response signals is to apply a demand signal that is independently generated by the HVAC controls.

4.3.2 Intel Development Work

In the course of researching "Smart" power meters,13 Michael Breton of Intel's Folsom Innovation Center contacted SMUD in February 2005 and learned of SMUD's interest in off-peak over-cooling. Intel proceeded to develop a prototype system that could communicate with both a smart utility meter and the home's thermostat. An Internet link provided two-way communication to give the homeowner and the utility local and remote access to meter data and thermostat settings.

Schematically, the system would appear as shown in Figure 5. The central platform in the home is a computer connected to the television that is used for viewing information. Home automation and specialized software is used to collect and store data from the thermostat and house electric meter. Internet access transfers data to and from the utility. Either radio frequency or power line carrier communications can be used for meter data transfer. Itron meters provided with electronic metering and readers were used for demonstrating the system. The reader, or receiver, connects to the PC using a USB port.

The X-10 PLC protocol was used for thermostat communications. Breton noted that due to reliability problems, the Universal Powerline Bus (UPB) would have been preferable, but no UPB thermostats were available at the time. A Smarthome USB-based x10 interface with Smartlink software was used to convey the PLC signal to the computer. HAL2000 software from Automated Living was used to log, accumulate, and report data that can be viewed on the home's TV. A custom Perl application was used to demonstrate how HAL could "watch" the utility website for demand response signals. More detail regarding software applications is provided in the Breton report, included in Appendix B. Information is accessible to the

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13. A "Smart" power meter contains a logic chip and communications capabilities.

homeowner through a screen display as shown in Figure 6. Homeowners can also view their expected electric bills under different rates, including an optional Time of Use (TOU) rate.

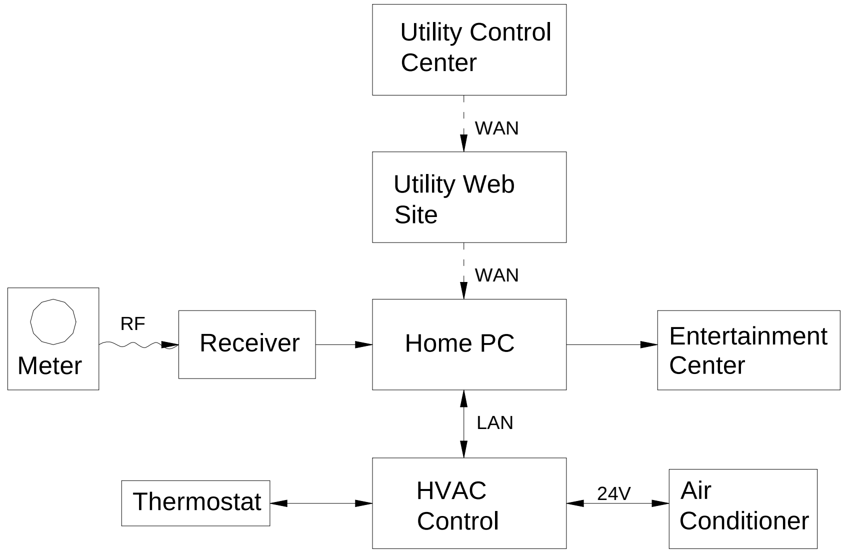

Figure 5: Intel Prototype Demand Response System

Photo Credit: Davis Energy Group

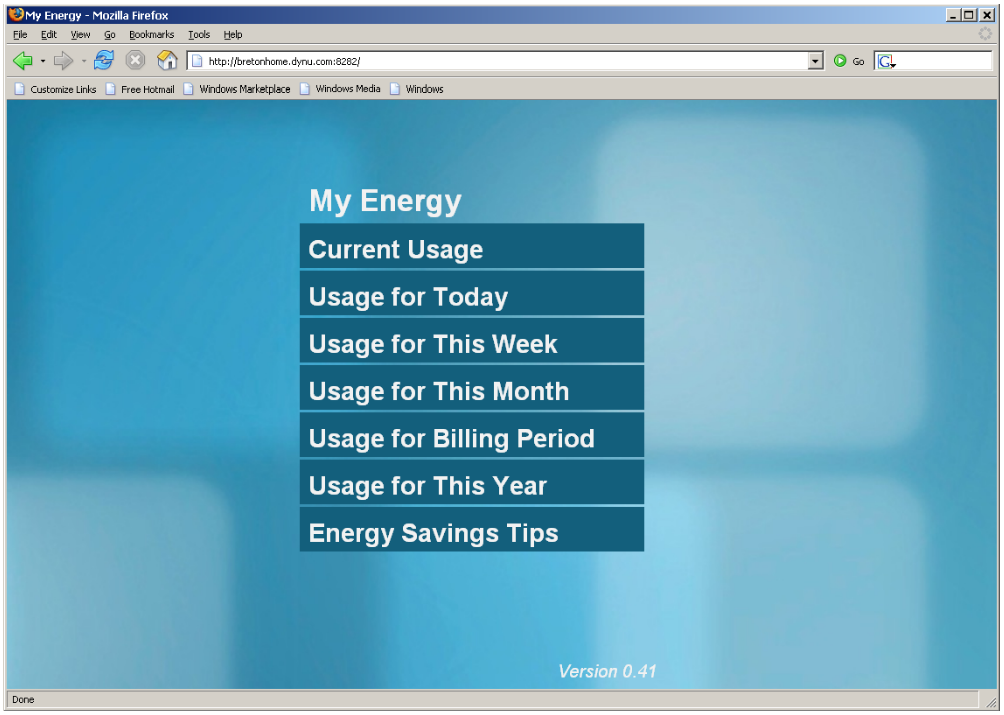

Figure 6: Intel's Information Access Display

Photo Credit: Davis Energy Group

Despite problems with the x10 communications, the Intel system was shown to provide a workable solution. The Intel system demonstrated the feasibility of not only enabling utilities to issue demand response signals to alter thermostat settings, but also providing feedback to both the utility and the homeowner. The system could potentially give homeowners the flexibility to select from alternate demand response programs or to unsubscribe from those programs. The substitution of smart meters to provide the gateway will likely provide a more secure means of communication that is more reliable from the utility perspective.

Chapter 5:
Stand-Alone System Design and Testing

In 2005, DEG was completing the PIER-funded NightBreeze gas furnace development project as the SMUD Over-cooling Project was beginning. SMUD's significant interest in air conditioner pre-cooling contributed to DEG's introduction of a NightBreeze pre-cooling control option in the late stages of the PIER project. The concept allows air conditioner pre-cooling to be scheduled to a daily varying setpoint (dependent on weather severity) over a user-defined period. Figure 7 shows a photo of the key pre-cool input section of the NightBreeze thermostat. By combining efficient night ventilation cooling and air conditioner pre-cooling, on-peak cooling operation and overall cooling energy use can hopefully be minimized.

The two-zone NightBreeze gas furnace control was extensively tested in both laboratory and field environments. A thermostat test stand was developed with a PC interface to allow direct review of system inputs and outputs. This proved especially valuable in quickly diagnosing control issues. DEG worked closely with controls provider RCS to correct observed programming issues. Once lab testing indicated the control was operating consistent with design intent, several systems were installed and monitored in the field. Field monitoring adds a new level of complexity to control testing as unexpected combinations of "real world" events results in unique control scenarios. Several months of field monitoring allowed DEG to resolve and address the remaining control issues. This work was completed in October 2006, which unfortunately precluded evaluating the control under the 2006 project field monitoring phase.

Figure 7: NightBreeze Thermostat Pre-Cool Settings

Photo Credit: Davis Energy Group

5.1 DOE2 Evaluation

DOE2 is a highly regarded hourly building energy simulation tool providing great flexibility in modeling building components, thermal mass elements, and HVAC systems, as well as incorporating custom modeling functions for advanced system types. In the mid-1990s, as part of the California Institute for Energy Efficiency's Alternatives to Compressor Cooling project, Joe Huang of Lawrence Berkeley National Laboratory added a custom function to model the predictive vent target algorithm incorporated in the NightBreeze controls. NightBreeze performance can then be evaluated in conjunction with various AC pre-cooling strategies to determine the best operating strategy from an energy, demand, and operating cost perspective.

Preliminary DOE2 modeling was completed in August 2006 to evaluate preferred thermostat settings for the 2006 field monitoring study. Additional analysis was completed in the spring of 2007 to refine the 2006 study.14 The 2007 DOE2 evaluation was completed based on a two-story, 2,182 sq. ft. house that was previously monitored and analyzed by DEG. The house is representative of many homes built in the Sacramento area in the late 1990s. Insulation levels are common of newer homes, but lower air conditioner efficiency, lack of tight ducts, and clear glazing reduces cooling performance relative to homes built under current Title 24 Standards15.

DOE2 runs were completed in the Sacramento climate assuming 80°F cooling setpoint and a 68°F NightBreeze lower limit ventilation target temperature. Parametrics were then completed to assess the length of the air conditioning pre-cooling time window (9 a.m. to 5 p.m., noon to 5 p.m., and 2 p.m. to 5 p.m.), and the level of air conditioner pre-cooling (3, 4, or 5°F above the daily calculated ventilation cooling temperature16). The DOE2 Sacramento hourly weather file was used in completing the analysis.17

5.2 Monitoring

The field-testing portion of this project was originally broken into two components:

- Proof of concept demand response testing at the Intel houses in 2005.
- Pre-cooling performance testing at five Sacramento area houses in 2006.

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14. As presented later in this report, the 2007 modeling study extended the optimal pre-cooling time window from 1 to 5 p.m. to noon to 5 p.m.

15. New homes built in the Sacramento area typically have 13 SEER air conditioners, low leakage ducts (6% of system airflow), and low solar heat gain windows.

16. On the hottest days, the control will select a 68°F vent cooling target, while on milder days the target may be 72°F. The 3-5°F offset would apply to the daily calculated vent target.

17. The standard DOE2 weather files are based on long-term data summaries and may not adequately represent heat storm events where daily high and low temperatures are elevated for three or more consecutive days.

The Intel testing focused more on thermostat control and web-based data handling, while the 2006 testing was structured to collect real world performance data on pre-cooling strategies. This was largely due to Intel's focus on testing the connectivity capabilities of the utility side demand response equipment (communicating meters and thermostats), which took priority over collecting pre-cooling test data under fairly controlled test protocol. The 2006 field test was formulated to generate data that would show the energy and demand impacts of pre-cooling strategies. Changes in SMUD project team management and the resulting setbacks in clearly defining the scope of work delayed the field test monitoring equipment installation until August 2006.

The goal of the 2006 field monitoring was to see how various strategies would work in conjunction with SMUD's pilot PSP TOU rate.18 The PSP rate features a weekday 5 to 8 p.m. super peak period, with shoulder peaks extending from noon to 10 p.m. The PSP rate closely reflects average SMUD TOU generation/delivery costs. Table 3 shows the schedule and rates for the PSP program. Weekend and holiday energy consumption is billed as off-peak. With a relatively small rate differential between on-peak and super peak periods, pre-cooling energy consumption patterns may prove difficult for homeowners to achieve bill neutrality.

Table 3: SMUD TOU pilot: Power Saver Plus (PSP)19

Period	Time period	Summer (July & Aug)	Swing (June & Sept)	Winter (Oct-May)
Off-Peak	10 p.m. – noon	$0.0835	$0.0759	$0.0688
On-Peak	Noon – 5 p.m., 8 – 10 p.m.	$0.1706	$0.1255	$0.0901
Super-Peak	5 – 8 p.m.	$0.2247	$0.1491	$0.0100

Source: Davis Energy Group

5.3 2005 Proof of Concept Testing

In early 2005, before SMUD completed a contract with DEG to complete this study, Intel approached SMUD regarding Smart Meters, or power meters that can be read via a home personal computer. As part of the SMUD / Intel connection, Intel developed a prototype system that could communicate with both a smart utility meter and the home's thermostat. An Internet link provided two-way communications, allowing the homeowner and the utility to locally and

18. The PSP rate is currently being tested in a 200-home pilot study.

19. The PSP rate includes a stepped bill adjustment based on total monthly usage. For low users (Less than 700 kWh/month), a 15% bill reduction is included. High users experience a 50% bill premium on monthly usage exceeding 3000 kWh.

remotely access meter data and thermostat settings. Home Automation and other specialized software could be installed to collect, normalize, store, and display temperature readings, as well as whole house energy usage. Internet access is also used to transfer data upstream as well as to provide remote access to data and control systems.

5.4 2006 Pre-Cooling Field Test

A project team meeting was held May 31, 2006, between SMUD, DEG, and Intel to structure a 2006 field-testing approach that would obtain data to supplement the 2005 Intel data. DEG proposed the idea of evaluating ventilation cooling as an efficient means of augmenting air conditioner pre-cooling. The team concurred and DEG approached the major Northern California HVAC contractor (Beutler Heating & Air) to obtain a list of potential candidate monitoring sites for projects that included high efficiency furnaces with electronically commutated motors20 (ECM) and SmartVent systems installed. The NightBreeze controls were to be retrofitted later in the summer based on completion of a PIER-funded project21 developing the multi-zone gas furnace NightBreeze control.

5.5 Home Selection

With delays in identifying and screening potential sites, the list of prospective candidates did not reach DEG until mid-July. SMUD then mailed introductory letters to 16 of the homeowners on the list, and collected a list of potential participants. A subset of five newly constructed homes was chosen in two regions south of Sacramento: Elk Grove and Wilton. The Elk Grove houses were constructed using industry standard specifications for energy efficiency measures. The Wilton homes were part of a SMUD energy efficiency program, and had extra insulation and high efficiency heating and cooling systems. Table 4 lists key characteristics of the five houses. All of the five sites included SmartVent systems with ECM furnace blower motors.

Table 4: Construction Characteristics of the Monitored Homes

House ID	Location	Year built	Floor Area	# of Stories	Wall Construction	Glazing
1	Elk	2002	2100	1	2x4 (R13)	Vinyl, clear
2	Elk	2005	2700	2	2x4 (R13)	Vinyl, clear
3	Wilton	2005	4400	1	2x6 (R19) + 1”	Vinyl, low
4	Wilton	2005	2873	1	2x6 (R19) + 1”	Vinyl, low
5	Wilton	2006	4400	1	2x6 (R19) + 1”	Vinyl, low

Source: Davis Energy Group

20. Needed for conversion to NightBreeze controls.

21. The “NightBreeze Product Development” project developed two-zone gas furnace NightBreeze control systems. More information at: http://www.energy.ca.gov/pier/buildings/projects/500-02-026-0.html

5.6 Monitoring Strategy

The pre-cooling set points and strategies were developed based on results of the DOE2 analysis. The results of the DOE2 analysis indicated that the benefits obtained from pre-cooling the house for six hours versus four hours was very minor compared to the negative effects of increased energy use. For this reason a four hour pre-cooling period (1 to 5 p.m.) was chosen. The simulations also showed that the maximum peak shift with the minimum overall consumption impact was with the higher pre-cooling set point. The homeowners' comfort thresholds (75° for the low, 80° for the high) further constrained the pre-cooling set point choices. Since the 5° temperature difference showed favorable results in the DOE2 simulations, it was chosen for the field study.

Test Phases

Three test phases were selected to test the effectiveness of pre-cooling on peak load shifting and overall homeowner economics.

Phase 1: Phase 1 was the benchmark ("base case") for comparison to other phases. The thermostat would be programmed with the homeowners' standard settings, with the SmartVent system disabled. The home was to be operated in Phase 1 for a minimum of two weeks.

Phase 2: Phase 2 introduced an air conditioner pre-cooling schedule using the home's programmable thermostat. This schedule pre-cooled the house 5° below setpoint from 1 to 5 p.m. daily22 to prepare for SMUD's 5 to 8 p.m. Super-Peak.

Phase 3: Phase 3 added night ventilation cooling to Phase 2 operation with a night ventilation target temperature of 68°F for all houses.

Monitoring System Description

The installed monitoring systems included both sensors wired to a central datalogger, as well as standalone, remote temperature/relative humidity loggers. The primary reason for this dual approach was that the houses were already completed, making wiring access to preferred indoor temperature and relative humidity sensors difficult to implement. The solution was to use hardwired sensors where possible (furnace power, compressor power, and outdoor temperature) and HOBO stand-alone loggers for indoor temperature and relative humidity. Since manual downloads were required for the stand-alone sensors, a direct connection to the datalogger was not pursued due to the time and expenses associated with installing modem phone lines.

The monitoring system consisted of a Datataker DT50 datalogger for monitoring condenser unit power, fan power and ventilation damper status, and HOBO temperature/RH sensors for indoor and outdoor environmental conditions. Data points were collected at 15-minute intervals

22. The 1 to 5 p.m. pre-cooling period was determined based on DOE2 modeling completed in August 2006.

and downloaded at the end of each phase. Table 5 lists the parameters measured and the types of sensors used.

Table 5: Monitoring Parameters

Monitoring Point	Type of Sensor	Units
Air Handler Energy	RIS PM-1000	kW, kWh
Condensing Unit Energy	RIS PM-1000	kW, kWh
Ventilation Damper Status	24VAC relay	% time open
Indoor Temperature and RH	HOBO Temp/RH	°F, %RH
Outdoor Temperature	Type T thermocouple or HOBO	°F

5.7 Wind Assessment

The following strategy was followed to quantify the benefits of pre-cooling as a synergistic strategy to enhance SMUD Solano wind farm generation characteristics:

Obtain an hourly June through September Microsoft Excel file from SMUD documenting 2004 data including outdoor dry bulb temperatures, hourly predicted wind generation (MW), and hourly actual wind generation (MW).

Estimate the hourly indoor temperature profiles and resulting air conditioner energy consumption for a new home based on the hourly outdoor temperature profiles. Complete this calculation for both conventional fixed setpoint cooling (Mode 1) and also for a combined AC/night ventilation cooling (Mode 3).

Determine the demand impacts of the pre-cooling strategy relative to the conventional fixed setpoint assumption.

Compare the hourly wind shortfall for hours in which wind production falls short of the "day ahead" forecast (shortfall = actual wind generation – predicted wind generation) to the demand impact calculated in Step 3 to determine if the pre-cooling strategy is beneficial.

Estimate the number of pre-cooled homes needed to balance the hourly shortfall.

Chapter 6: Project Outcomes

6.1 Hardware

Work completed by Intel showed the potential for web-based communications to be used to control special communicating thermostats. Other gateways into the control of HVAC systems were discussed, such as the Energy Commission's initiative to develop communicating thermostats to facilitate real time pricing strategies, and the opportunity to use the communicating capability of AMI meters being evaluated in investor-owned utility pilot programs. No infrastructure is currently in place to allow the use of a utility signal to modify thermostat settings (as opposed to the simpler cooling cycling control). The alternative to dependence on a utility-generated signal is to apply a demand signal that is independently generated by the HVAC controls. The NightBreeze thermostat does have an RS485 interface that could be used in the future when the infrastructure is developed.

6.2 DOE2 Evaluation

Table 6 summarizes energy usage, peak demand, and operating costs (under the PSP pilot rate) projected in the May 2007 DOE2 evaluation. Results are shown for the base case run, "NightBreeze-only" run (no air conditioner pre-cooling), and the nine "NightBreeze plus Pre-cool" cases evaluating variations in the amount of pre-cool temperature offset and pre-cool duration. DOE2 peak demand is an average hourly demand defined by the total hourly cooling load divided by the efficiency for that hour. With the assumed thermostat assumptions of 80°F with 68°F vent low limit temperature, the NightBreeze-only case is projected to save 2/3 of the base case cooling energy use, reduce super on-peak maximum demand by 24 percent, and summer homeowner operating costs by 43 percent under the existing PSP pilot rate.[23]

Adding air conditioner pre-cooling significantly increases cooling energy use relative to the NightBreeze-only case (in some cases exceeding the base case kWh), but significantly reduces super on-peak cooling kWh and demand. In fact, in most cases, super on-peak cooling demand is completely eliminated. The 2 to 5 p.m. pre-cooling period is projected to be too short to allow the house to coast through the peak period. In terms of homeowner electric costs, the 3°F offset was found to result in higher operating costs in two of the three cases. DEG identified the Case 6 pre-cooling scenario as the preferred strategy based on balancing projected peak demand reduction with homeowner operating cost savings. With a 5°F offset, AC pre-cooling temperatures will never be below 73°F (68 low limit plus 5 degree offset), a setting that would hopefully be palatable to a segment of the population. Relative to the base case, Case 6 is

23. It should be noted that the DOE2 weather file has no days hotter than 103°F, and no night with a minimum temperature above 67°F. Weather monitoring during the past 15 to 20 years increasingly reveals heat storms in which highs of 107°F and above and daily lows of 80°F were observed.

projected to reduce total cooling energy use by 24 percent, super peak energy use by 97 percent, and summer utility bills by 21 percent.

Table 6: DOE2 Parametric Results Summary

	PreCool	PreCool	Cooling	Super Onpeak		May-Oct	
Case	Offset	Period	kWh	Clg kWh	Clg kW	Elec $	Savings $
Base	--	--	1,825	467	4.96	$ 516	--
NB	--	--	612	139	3.78	$ 294	$ 222
1	3	9AM-5PM	2,312	6	0.00	$ 568	$ (52)
2	4	"	1,856	7	0.00	$ 479	$ 37
3	5	"	1,463	8	0.00	$ 405	$ 111
4	3	12-5PM	2,084	8	0.00	$ 524	$ (8)
5	4	"	1,713	10	0.00	$ 442	$ 74
6	5	"	1,385	15	0.14	$ 405	$ 111
7	3	2-5PM	1,728	41	1.82	$ 446	$ 69
8	4	"	1,473	44	1.83	$ 413	$ 103
9	5	"	1,230	47	1.85	$ 386	$ 130

Source: Davis Energy Group

Figure 8 plots the DOE2 projected peak day temperature and hourly demand for the base case run and the preferred Case 6 run (Noon to 5 p.m. pre-cooling period, with 5°F offset). The data shown represents the 103°F peak day on the weather tape and the preceding 97°F day. The NightBreeze plus pre-cooling strategy fully eliminated super peak cooling operation on the first day and nearly eliminated it on the second day. Total cooling energy consumption during the two days was 30 percent lower for the NightBreeze plus air conditioner pre-cooling case (71 vs. 50 kWh). Results would likely be different during a heat storm event where outdoor low temperatures may not fall below 75°.

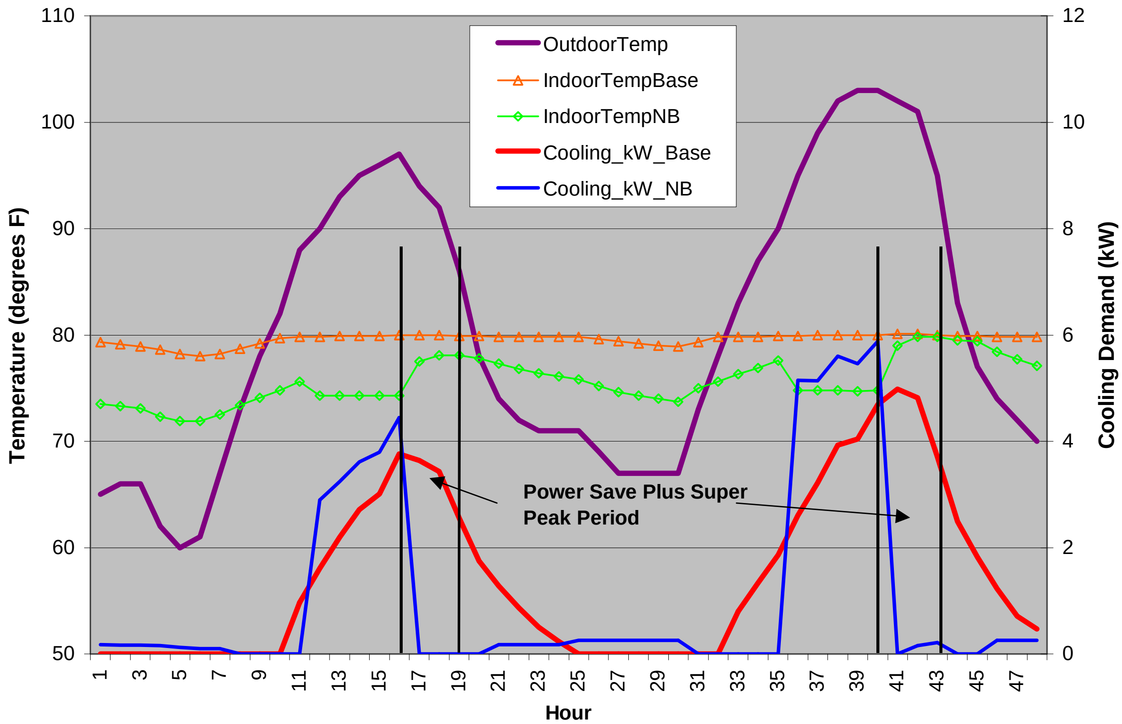

Figure 8: DOE2 Projected Peak Day Performance (Base Case and NB plus Pre-Cooling)

Photo Credit: Davis Energy Group

6.3 Monitoring

Although the 2006 testing originally planned for three weeks of data collection in each mode, the late summer monitoring initiation forced the schedule to be compressed to two weeks per test phase to increase the likelihood that all three phases would be tested under similar weather conditions before fall weather arrived. Table 7 documents the proposed 2006 monitoring schedule.

The programmable SmartVent thermostats were used for controlling the pre-cooling schedules for Phases 2 and 3 of the study. Figure 9 plots the typical daily variations in the thermostat setpoints. There were some minor variations among the sites to accommodate personal preferences.

Table 7: Monitoring Schedule

Operating Mode	Period
Phase 1	August 14 – 27
Phase 2	August 28 – September 10
Phase 3	September 11 – 24

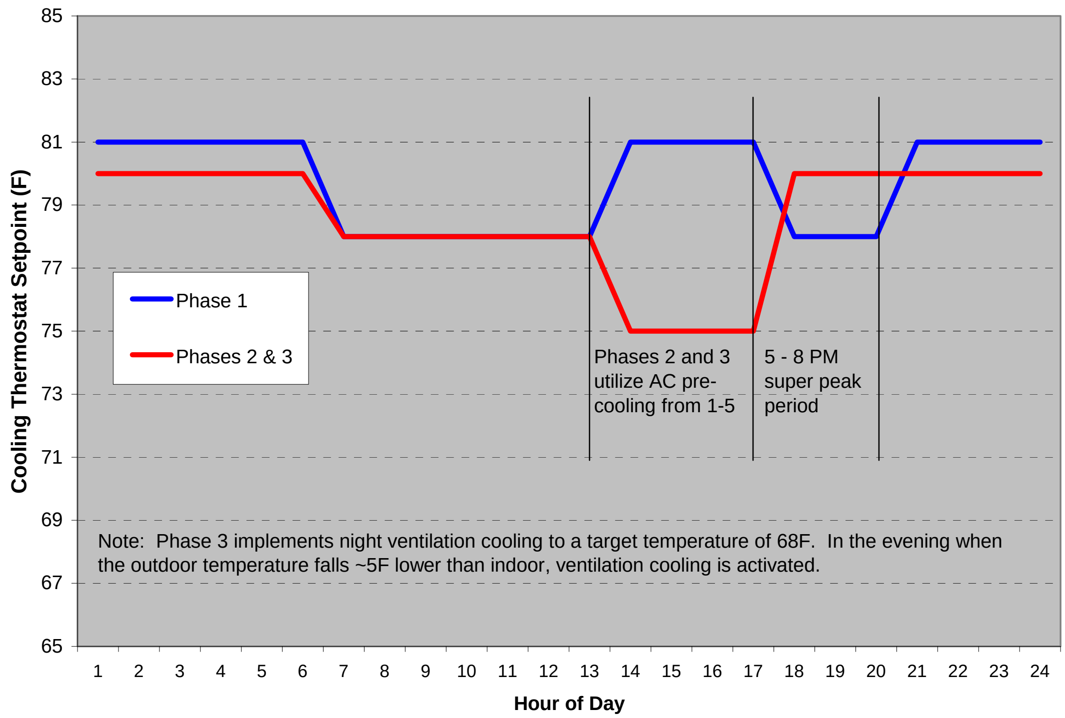

Figure 9: Thermostat Setpoints During 2006 Field Monitoring

Photo Credit: Davis Energy Group

The data collected for each house was imported into an Excel workbook. The data was then processed with the following steps to extract the useful information:

Step 1: Calculate daily cooling degree days based on the average daily temperature minus the base 65°F value (CDD65).

Step 2: Tabulate air handler and condensing unit energy by off-peak, on-peak, and super-peak time periods.

Step 3: Plot daily cooling energy consumption for each phase using daily CDD65 values as the independent variable. Linear trend lines are established for each phase as shown in Figure 10.

Step 4: Extrapolate full season cooling energy usage by TOU period using 30-year historical CDD65 daily data for Sacramento.

Step 5: Calculate monthly SMUD bills under the Power Save Plus rate for each of the monitored houses and the three phases.

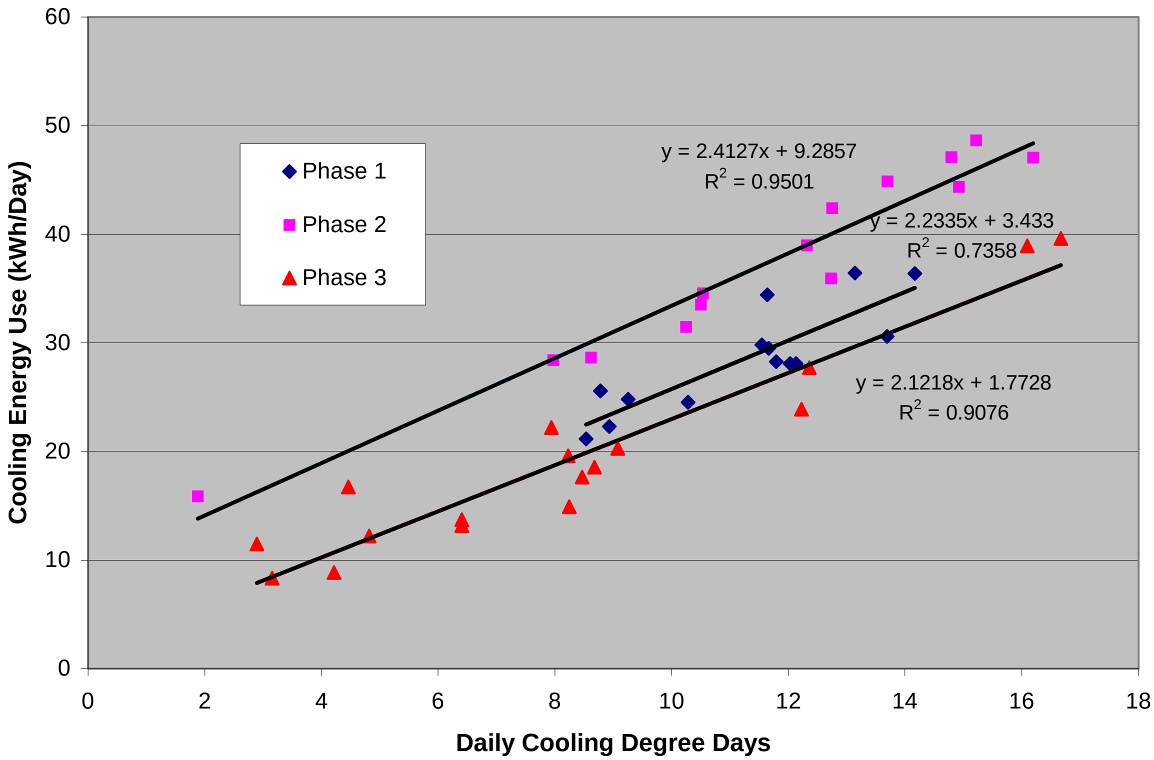

Figure 10: Total Daily Energy Use vs. CDD65 (House No. 3)

Photo Credit: Davis Energy Group

This process was used for each of the houses and also to disaggregate total energy usage into off-peak, on-peak, and super on-peak components. In reviewing the analyzed data it became clear that only two of the five houses had data suitable for detailed evaluation. One of the houses was a very low cooling energy consumer making trending very difficult, and the other two suffered from missing data and homeowner modifications of the prescribed thermostat setpoints.

Another significant problem the research team encountered after completing monitoring was the air handler airflow level used in SmartVent operation was found to be very low for purposes of night ventilation cooling. As DEG learned from Beutler Heating and Air during the Phase 3 data review, furnaces equipped with advanced ECM motors24 typically have a low

24. This only occurs with variable speed furnace motors.

manual fan speed setting, affecting the capability of ventilation cooling to reduce indoor temperatures. Typical night vent air handler was monitored at less than 300W, or less than 40 percent of normal cooling fan speed. The lower fan speed reduces the effectiveness of the ventilation cooling since less air is moved through the house.

In general, Phase 3 data was of questionable value for all houses due to milder than usual weather through the month of September. Only three days during Phase 3 testing experienced outdoor high temperatures above 90°F. Figure 11 plots National Weather Service high, low, and mean temperatures for Sacramento for the two-month period during which testing occurred. The cooler than normal daytime highs and lower nighttime lows complicated Phase 3 comparisons to the other test phases. The few hot Phase 3 days did yield a trend that followed expectations and is therefore presented; however, Phase 3 projections should be validated with further testing before conclusions are drawn on ventilation cooling performance.

The final step in the evaluation process was to take 30-year Sacramento climatological data to project typical full cooling season impacts based on the regression results for Houses 2 and 3. The CDD values for each month were used to project monthly cooling energy use and total household utility bills under the PSP rate structure.

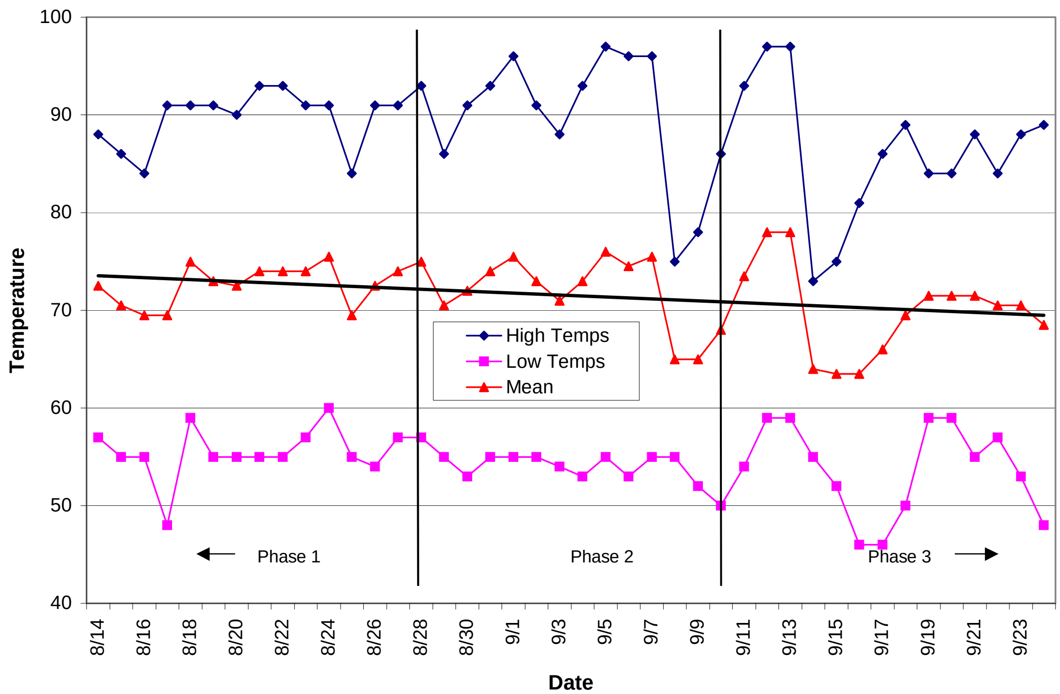

Figure 11: 2006 National Weather Service Sacramento Data

Photo Credit: Davis Energy Group

Table 8 tabulates energy consumption projections for Houses 2 and 3, and Figures 12 and 13 present full cooling season energy usage by TOU period. In the Super Peak period, House No. 2 is projected to consume 57 percent less than the baseline in AC pre-cooling operation and 92 percent less in night ventilation plus AC pre-cooling operation. Similarly, House No. 3 is projected to save 73 percent and 81 percent, respectively. Overall, cooling energy consumption for night ventilation plus AC pre-cooling operation is projected to be 29 percent lower for House No. 2 and 12 percent lower for House No. 3.

Table 8: Projected Full Season Cooling Energy Use (kWh)

	House No. 2			**House No. 3**		
	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
Total Use	2702	3485	1938	4049	5400	3573
Energy Breakdown by Power Saver Plus TOU Periods						
Off-Peak	1153	1607	717	1445	2838	1575
On-Peak	538	1448	1141	1715	2190	1762
Super-Peak	1011	430	83	1411	388	264
Energy Savings % vs. Phase 1 Base Case						
Off-Peak	--	+39%	-38%	--	+96%	+9%
On-Peak	--	+169%	+112%	--	+28%	+3%
Super-Peak	--	-57%	-92%	--	-73%	-81%

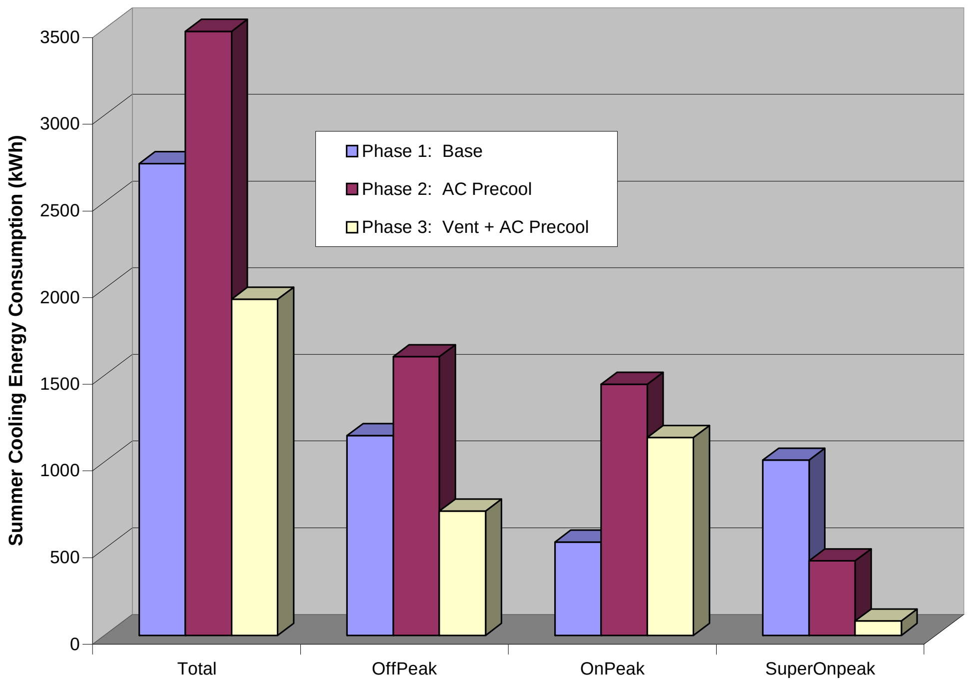

Figure 12: Full Season Cooling Energy Consumption (House No. 2)

Photo Credit: Davis Energy Group

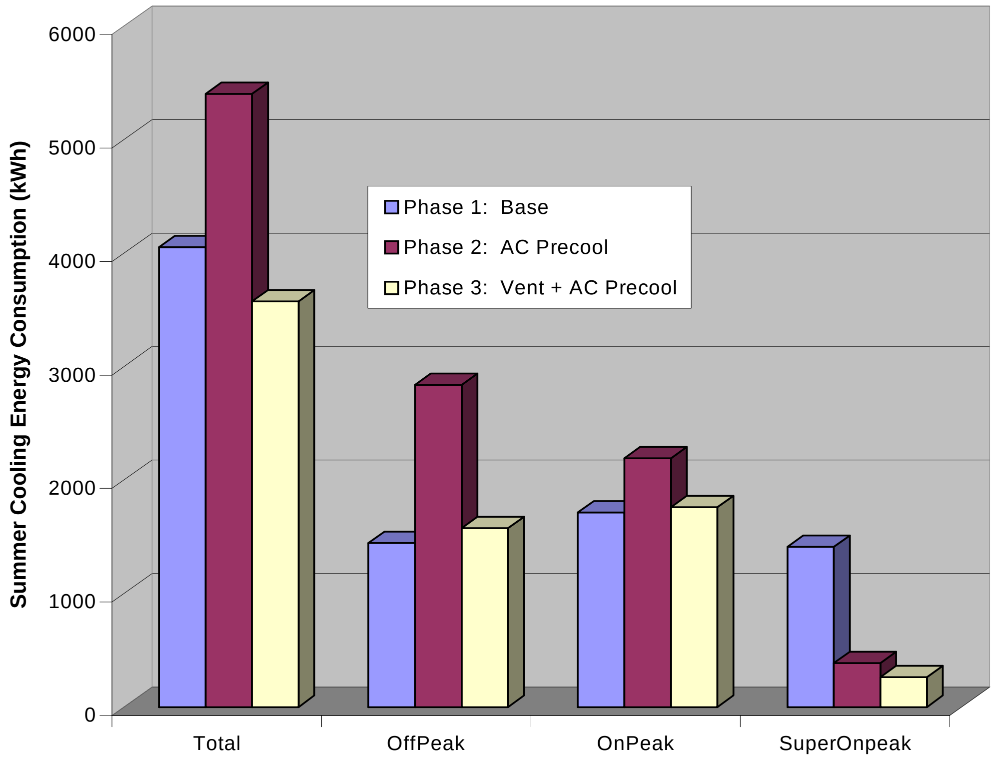

Figure 13: Full Season Cooling Energy Consumption (House No. 3)

Photo Credit: Davis Energy Group

The primary focus of the field monitoring was to assess how the various pre-cooling strategies would affect Super Peak usage on the pilot PSP schedule since this rate structure best represents SMUD's costs of providing service to its residential customers. In addition, the adjusted cooling usage profiles with pre-cooling must demonstrate favorable customer economics if a program offering is expected to be attractive to customers. Cooling season costs for the standard SMUD utility rate and the PSP pilot rate are summarized in Table 9 below. Phase 3 projections indicate savings for both rate structures, with estimated savings of $119/year for House No. 2 (31 percent) and $215 for House No. 3 (27 percent) under the pilot PSP rate.

Table 9: Projected Annual Cooling Energy Cost (Houses 2 and 3)

House No. 2			
Rate	Phase 1	Phase 2	Phase 3
Standard	$ 374	$ 450	$ 275
PSP	$ 378	$ 442	$ 259
House No. 3			
Rate	Phase 1	Phase 2	Phase 3
Standard	$ 676	$ 884	$ 599
PSP	$ 786	$ 804	$ 571

Source: Davis Energy Group

Unfortunately, the 2006 field monitoring did not fully provide conclusive results on pre-cooling performance for the following reasons:

The late start in defining the test plan approach, selecting the houses, and installing the monitoring equipment resulted in shortened two week test phases in each mode of operation.

An early fall resulted in Phase 3 weather significantly cooler than Phases 1 or 2. With significantly cooler weather, it was difficult to accurately ascribe cooling energy savings to night ventilation operation since cooling loads were small to begin with.

Several of the occupants tended to override thermostat settings based on comfort issues or other factors, which complicated data comparisons.

The delayed completion of the NightBreeze PIER Development project did not allow advanced NightBreeze systems to be installed in the test homes. Low "manual fan" airflow levels that resulted in low ventilation cooling airflow volumes hampered all the existing SmartVent houses. The low airflow combined with the milder Phase 3 weather rendered the combined ventilation cooling plus pre-cooling data of marginal value.

To address this situation, the SMUD project manager and the consultant agreed to monitor a single NightBreeze home in 2007 using a similar test protocol to the 2006 testing. This testing, not originally in the project scope, was added to bolster the monitoring aspect of the project. The home, owned by a SMUD customer, is a 2,850 sq. ft., two-story house located in Folsom, east of Sacramento. The house was originally built in the early 1990s, but energy efficiency measures were significantly upgraded in 2006. A home performance contractor completed the following upgrades:

Building envelope upgraded with envelope tightening, kneewall insulation, added ceiling insulation (to R-40), and draft-stopping of interior cavities.

HVAC system upgraded with 96 percent AFUE furnace, right sized (2 ton) high-efficiency evaporative condenser, and NightBreeze ventilation cooling system.

Duct system modifications to improve air delivery, increase register throw, enhance duct insulation, and reduce measured leakage below 4 percent.

Monitoring equipment similar to that used in the 2006 testing was installed in late May 2007. Results of the 2006 monitoring coupled with the DOE2 simulation results suggested that the focus should be on the combined NightBreeze with air conditioner pre-cooling operation, since DEG found air conditioner pre-cooling was not cost-effective for the homeowners under either the standard SMUD rate or the PSP pilot rate.

Monitoring in 2007 included testing in the following modes:

<u>Mode 1: (May 23 to June 21)</u> NightBreeze operation with air conditioner pre-cooling from noon to 5 p.m.. Outside of the pre-cooling period, the AC setpoint was 78°F. Windows were closed during this test. The NightBreeze was set to operate at 1700 cfm (0.6 cfm/ft^2 of floor area), but the actual airflow was about 930 cfm since the furnace only had a 1/2 hp blower motor.

<u>Mode 2: (June 22 to July 10)</u> Standard AC operation with fixed cooling setpoint of 78°F. Windows were closed during this test. The homeowners were on vacation from June 29 through July 7.

<u>Mode 3: (July 11 to July 25)</u> NightBreeze operation with air conditioner pre-cooling from noon to 5 p.m. Outside of the pre-cooling period, the AC setpoint was 78°F. Windows were open during this test. On July 19, the NightBreeze unit was reprogrammed to provide the maximum ventilation air supply (about 1300 cfm).

<u>Mode 4: (July 26 to August 1)</u> NightBreeze operation with standard air conditioner operation (78°F cooling setpoint). Windows were open during this test.

<u>Mode 5: (August 2 to August 8)</u> Standard AC operation with fixed cooling setpoint of 78°F. Windows were open during this test.

<u>Mode 6: (August 9 to August 20)</u> NightBreeze operation with standard air conditioner operation (78°F cooling setpoint). The "vent delta temperature" (required differential between indoor and outdoor temperature to initiate and terminate NightBreeze operation) was reduced from 5°F to 3°F to allow more ventilation cooling to occur.

<u>Mode 7: (August 21^{st} to September 6^{th})</u> NightBreeze operation with air conditioner pre-cooling from noon to 5 p.m. Outside of the pre-cooling period, the AC setpoint was 78°F. Windows were closed during this test. NightBreeze airflow was maintained at 1300 cfm with a 3°F vent delta temperature.

Two key site-specific issues surfaced during the 2007 monitoring that affected the results to some degree. First, right-sizing of the condensing unit does reduce the ability of pre-cooling a house on very hot days when the system is struggling to maintain temperature.[25] Second, the installed furnace is smaller than typical for a house this size. The furnace, the smallest in the manufacturer's product line, has a 1/2 hp variable speed motor. Virtually all NightBreeze systems are installed with a 3/4 or 1 hp motor. The 1/2 hp unit can only provide approximately 1200 cfm of airflow, or about 0.42 cfm/ft^2, which is 30 percent below the 0.60 cfm/ft^2 level recommended in the NightBreeze installation manual.

Appendix C includes a summary of Sacramento National Weather Service Data for the full 2007 monitoring period with operating modes highlighted, and also time series plots of the collected data. Despite multiple NightBreeze test modes (primarily with, but also without pre-cooling), only Mode 7 included the preferred airflow level, ventilation cooling "delta temperature", and corrected fan speed ramp down. By chance, this period included some of the hottest weather of the summer ensuring that the operating data collected represented a wide range of conditions. For baseline comparison purposes, data from Mode 2 was selected. This base case data included periods that were occupied and also a vacation period. For the entire Mode 2 period, windows were not used for natural ventilation.[26]

Figure 14 plots data from the hottest day from the Mode 2 test,[27] the hottest day from Mode 7, and the preceding Mode 7 day. The graph is intended to reflect general performance trends and not necessarily provide a direct comparison. The three days had maximum outdoor temperatures ranging from 97 to 105°, with the 105° temperature recorded on the baseline day. The hottest Mode 7 NightBreeze plus Pre-Cooling ("NBPC2") day was preceded by a slightly milder day ("NBPC1"). Second floor indoor temperature profiles show a fairly constant 78 to 79°F indoor setting for the base case, with some ventilation cooling benefit on NBPC1, but little benefit on the second hotter day. Demand profiles for the three days highlight the operational differences. The base case shows light cooling usage after midnight, followed by increasing usage through the day, peaking during SMUD's 5 to 8 p.m. super peak period. The NBPC1 day shows continuous NightBreeze operation through the night with no air conditioner operation until the noon pre-cooling period. The air conditioner runs continuously and reduces indoor temperatures by about 2°F from noon to 5 p.m. During the super-peak period the cooling demand is zero. NBPC2 shows continuous through-the-night ventilation cooling operation, but there is little indoor temperature reduction, although conventional air conditioning operation is likely being offset by ventilation cooling operation. By mid-morning, air conditioner operation ensues and the unit runs continuously from noon to 5 PM in an effort to pre-cool the house. The

25. A normal Sacramento sizing of 700-800 ft^2/ton would provide roughly twice the pre-cooling capability than the test house (sized at 1400 ft^2/ton).

26. There is significant anecdotal data suggesting that natural ventilation impacts are overestimated by most building energy simulation models.

27. Homeowners were on vacation on this day.

right-sized condensing unit is unable to pull down indoor temperatures, resulting in some operation during the super-peak period.

From a comparative viewpoint, this data demonstrates the operating characteristics of conventional cooling relative to the pre-cooling strategy. On the first day of the pre-cooling operation, the NightBreeze is able to provide some ventilation cooling benefit resulting in delayed air conditioner operation, but on the second (hotter) day the ventilation cooling benefit is limited to offsetting through the night air conditioner operation. Table 10 summarizes energy consumption by TOU period for each of three days. The first day of NBPC operation, the cooling energy consumption was 21 percent lower than the (hotter) base case day, while on the second day, NBPC cooling usage was 4 percent higher. More significantly, the NBPC strategy was effective in shifting load off the super-peak period with energy use reductions ranging from 63 to 100 percent.

Table 11 summarizes full Mode 2 and Mode 7 data in terms of energy use by TOU period. Mode 2 included 19 days, 9 of which were vacation days with average usage per CDD approximately 20 percent lower than the occupied days. Mode 7 data included 16 days of operation. The milder Mode 2 weather skews the comparison since the kWh vs. CDD trend line for base case operation is steeper than for Mode 7. Without normalizing the data, overall energy consumption per CDD is 79 percent higher for Mode 7, but super-peak consumption is reduced by 80 percent.

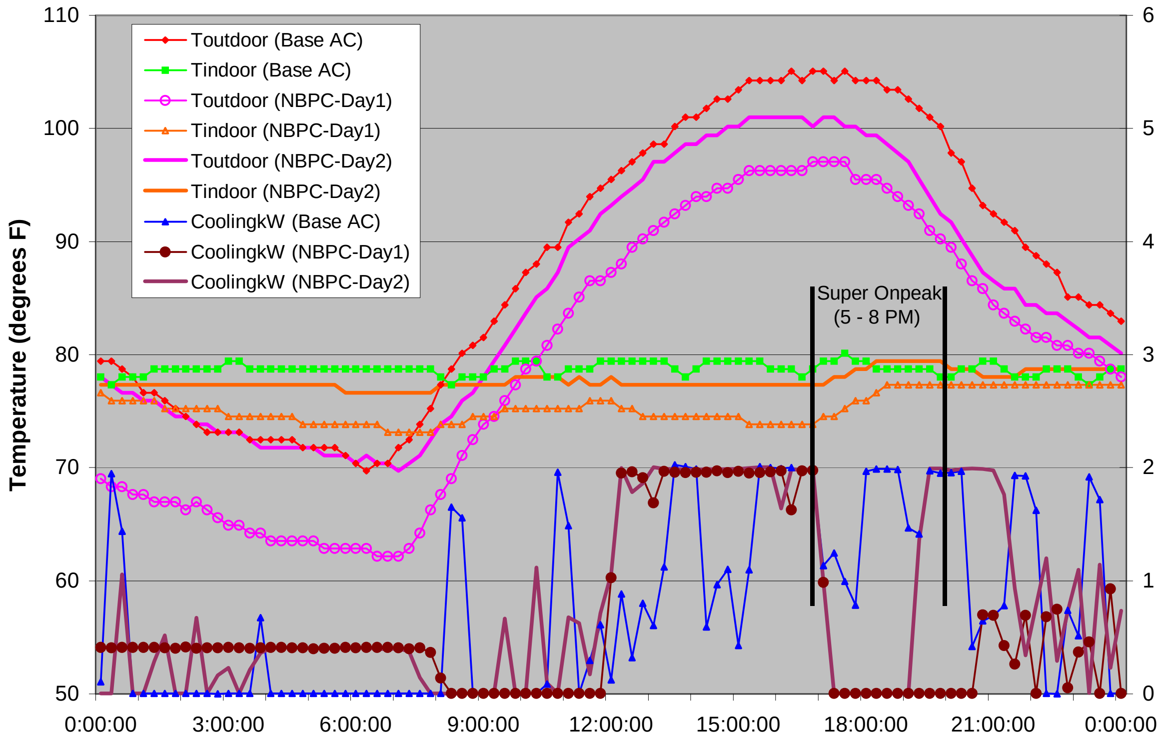

Figure 14: Comparison of Base Case and NB plus Pre-Cooling Operation

Photo Credit: Davis Energy Group

Table 10: Peak Day Performance Comparison

	Total	Energy by TOU Period (kWh)			Energy by TOU Period (%)		
Case	kWh	Offpeak	Onpeak	SuperOn	Offpeak	Onpeak	SuperOn
Base	18.4	4.2	9.3	4.9	23%	50%	27%
NB+PC 1	14.5	4.4	10.1	0.0	30%	70%	0%
NB+PC 2	19.1	4.8	12.5	1.8	25%	65%	10%

Source: Davis Energy Group

Table 11: Comparison of Mode 2 and Mode 7 Energy Consumption

	Average	Daily	Daily kWh/CDD by TOU Period			Energy by TOU Period (%)		
Mode	CDD	kWh/CDD	Offpeak	Onpeak	SuperOn	Offpeak	Onpeak	SuperOn
2	12.1	0.516	0.078	0.234	0.204	15.1%	45.4%	39.5%
7	16.8	0.924	0.280	0.602	0.041	30.3%	65.2%	4.5%
%	+39%	+79%	+259%	+157%	**-80%**			

Source: Davis Energy Group

Figure 15 plots daily energy consumption vs. CDD for Mode 2 (disaggregated for vacation days and when the occupants are home) and Mode 7. The plot highlights the tendency for excessive energy consumption on mild Mode 7 days due to unnecessary air conditioner pre-cooling, as well as the flatter Mode 7 slope due to ventilation cooling savings and air conditioner operation during more favorable times.28 At about 20 CDD, the flatter NBPC trend line intercepts the base case "home" trend line.

28. Ventilation cooling benefits would be higher in a home with a full-size furnace that could achieve the NightBreeze target airflow of 0.6 cfm/ft^2. In addition, a house using a conventional air-cooled condensing unit may show greater energy savings due to shifting operation to slightly cooler parts of the day and minimizing air conditioner cycling.

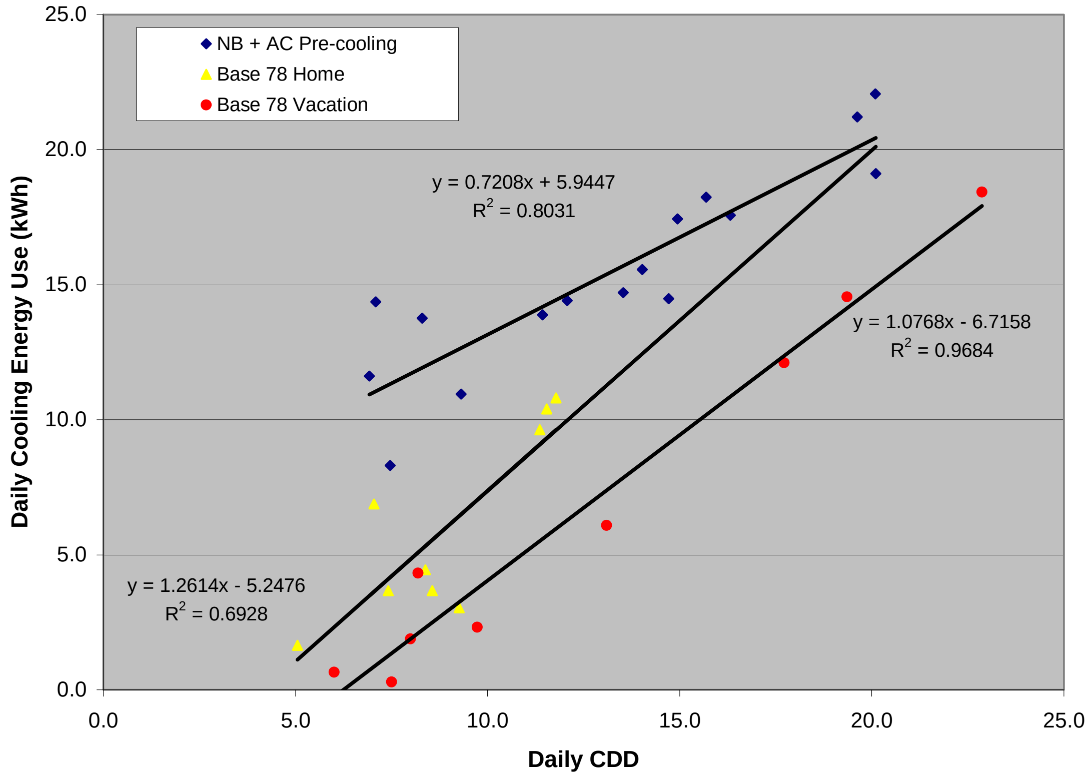

Figure 15: Comparison of Base Case and NB + Pre-Cooling Operation

Photo Credit: Davis Energy Group

The final step in the evaluation process is to extend the Figure 15 trend lines and TOU disaggregation to 2007 National Weather Service Sacramento data for the June through September cooling season. Running the trend relationships through identical weather takes care of the weather discrepancies that are reflected in Table 10. Figure 16 shows projected energy usage by TOU period for base case (windows closed) air conditioner operation vs. NightBreeze plus pre-cooling. June through September cooling energy consumption is projected to be 26 percent higher for NBPC (1339 vs. 1065 kWh), but super-peak consumption is projected to **88 percent lower** (38 vs. 315 kWh). Total June through September cooling costs are estimated at $149 for the base case operation and $158 for the combined NightBreeze plus pre-cooling operation. These results are specific to the application monitored; however, more favorable results may be anticipated for the following reasons:

The installed NightBreeze system was undersized for the home, providing only 70 percent of the manufacturer suggested ventilation air per sq. ft. of floor area.

Improvements in the NightBreeze pre-cooling algorithm would help reduce the excessive air conditioner pre-cooling on mild days when it is not needed.29

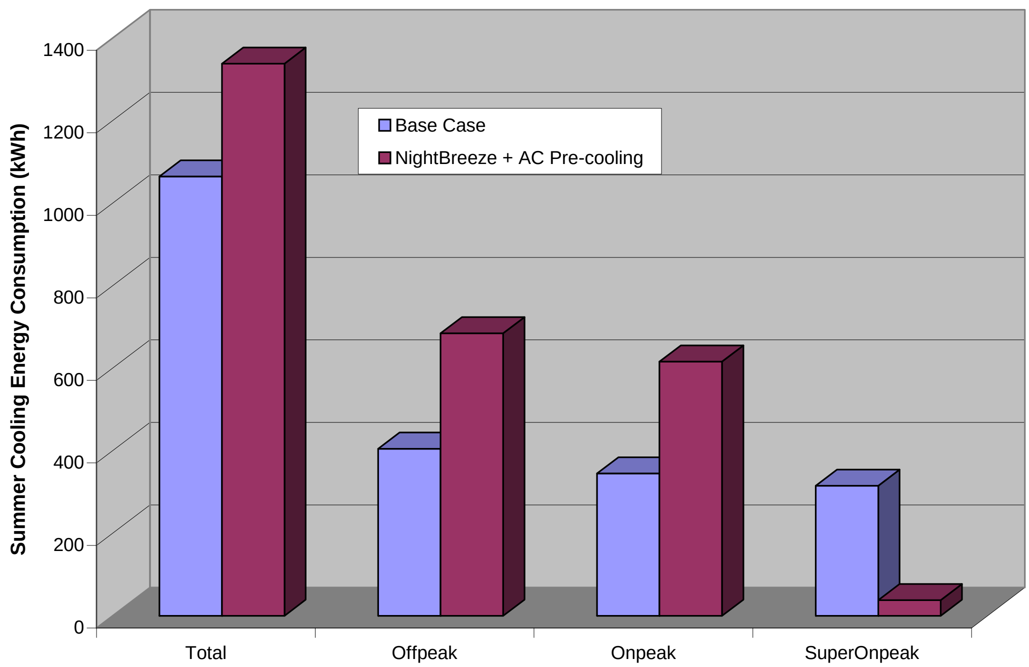

Figure 16: Projected June through September Cooling Energy Comparison

Photo Credit: Davis Energy Group

Although the 2007 monitoring results validate both the DOE2 modeling results and the 2006 results in terms of super-peak savings potential of 88 percent, the 2007 results do demonstrate a significant 26 percent total cooling energy penalty vs. DOE2 projected 24 percent savings. Both the undersized NightBreeze system in the 2007 field test and the excess air conditioner pre-cooling operation contribute to this energy penalty, but further study on a wider sample of homes is certainly warranted to better assess the impact on a more representative scale.

6.5 Wind Analysis

The June through September Solano Wind Project spreadsheet provided by the SMUD project manager included 2004 hourly Sacramento dry bulb temperatures, as well as hourly

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29. On average, the NightBreeze plus Pre-cooling monitoring data shows average indoor temperatures about 1°F cooler than the base case data (76.1° vs. 77.0°F), suggesting improved indoor comfort. On mild summer days, the pre-cooling is unnecessary, or a smaller level of pre-cooling would suffice.

predicted[30] and actual wind production. Although the 2004 summer was warmer than the long-term statistical average in terms of cooling degree days (1,313 degree days vs. long-term average of 1,248), the summer weather did not include the summer heat storm events associated with hot summers. Clearly a summer weather pattern such as 2004 would result in numerous "average" days, but few, if any, multi-day heat storm events. The lack of a heat storm event in 2004 would certainly impact how a pre-cooling approach might work. Further study of the wind data with multiple years of weather/wind is recommended.

The 2004 dataset was analyzed to determine patterns of wind generation and wind shortfall for each of the four summer months for the 102 MW wind farm. Figure 17 plots the average hourly generation profile for each of the months. Although there is daily variation common to wind systems, June through August demonstrate a fairly consistent pattern with September showing a slightly weaker wind resource. The shapes of the curves show a maximum in the 9 p.m. to 2 a.m. period and a minimum slightly after noon. The wind resource gains strength throughout the 5 to 8 p.m. super-peak period.

Figure 18 plots the hourly wind shortfall (or excess capacity) based on the day-ahead forecast. Interestingly the trend shows excess wind capacity from roughly 8 p.m. to 6 a.m. and a capacity shortfall during the middle of the day and much of the 5 to 8 p.m. super-peak period. This trend is encouraging in that air conditioner pre-cooling strategies with night ventilation cooling will shift electrical demand from on-peak hours to off-peak hours when excess wind capacity is generally available.

A BASIC computer model was developed to calculate hourly cooling demand to generate profiles for each of three modes of operation: Conventional AC, AC pre-cooling (5°F setpoint reduction) during 1 to 5 p.m., and night ventilation with 1 to 5 p.m. AC pre-cooling. Conventional AC operation was calibrated to a nominal seasonal cooling energy use of 1,300 kWh/year. AC pre-cooling was calibrated to 30 percent higher usage (about 1,700 kWh/year) based on 2006 monitoring conclusions and NightBreeze plus AC pre-cooling was calibrated to 20 percent lower usage (about 1,040 kWh/year) based on the DOE2 modeling study.[31]

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30. The predicted capacity for all 24 hours of the next day is generated at 6 a.m. the prior day.

31. These assumptions were based on the 2006 DOE2 modeling results with the 1 to 5 p.m. pre-cooling period.

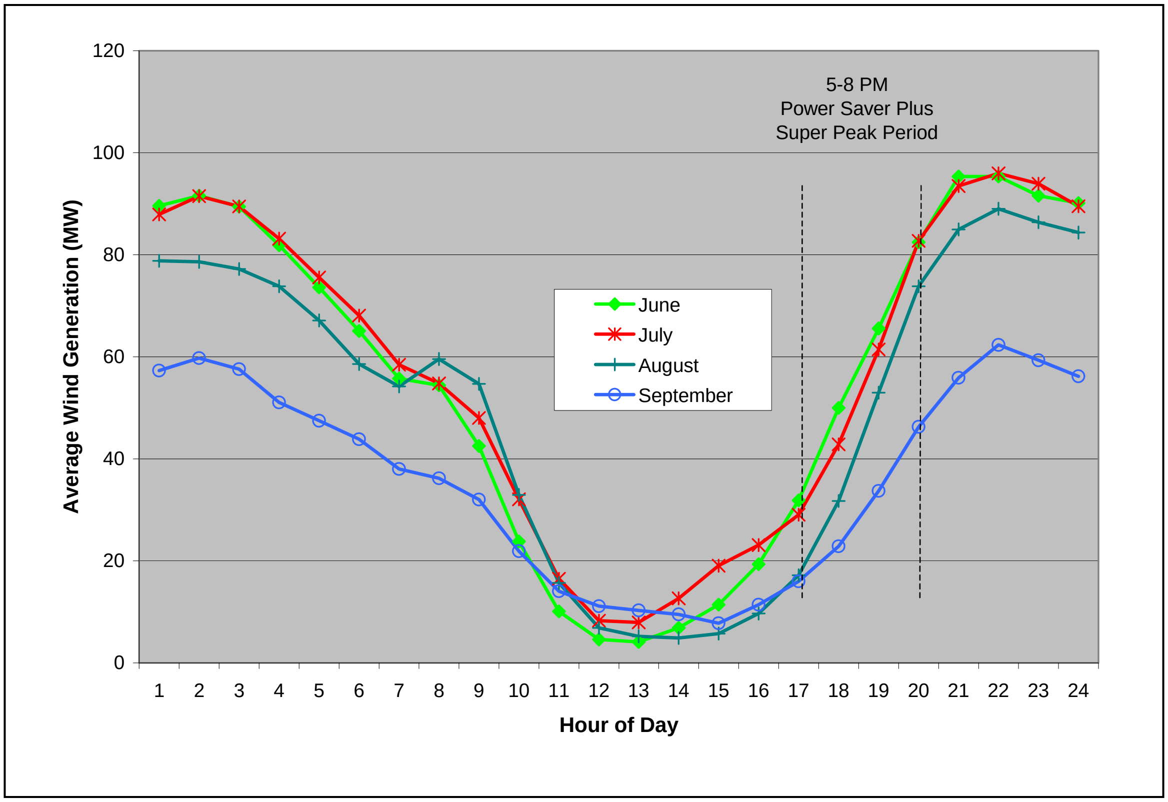

Figure 17: Daily Solano Wind Generation Profile by Month

Photo Credit: Davis Energy Group

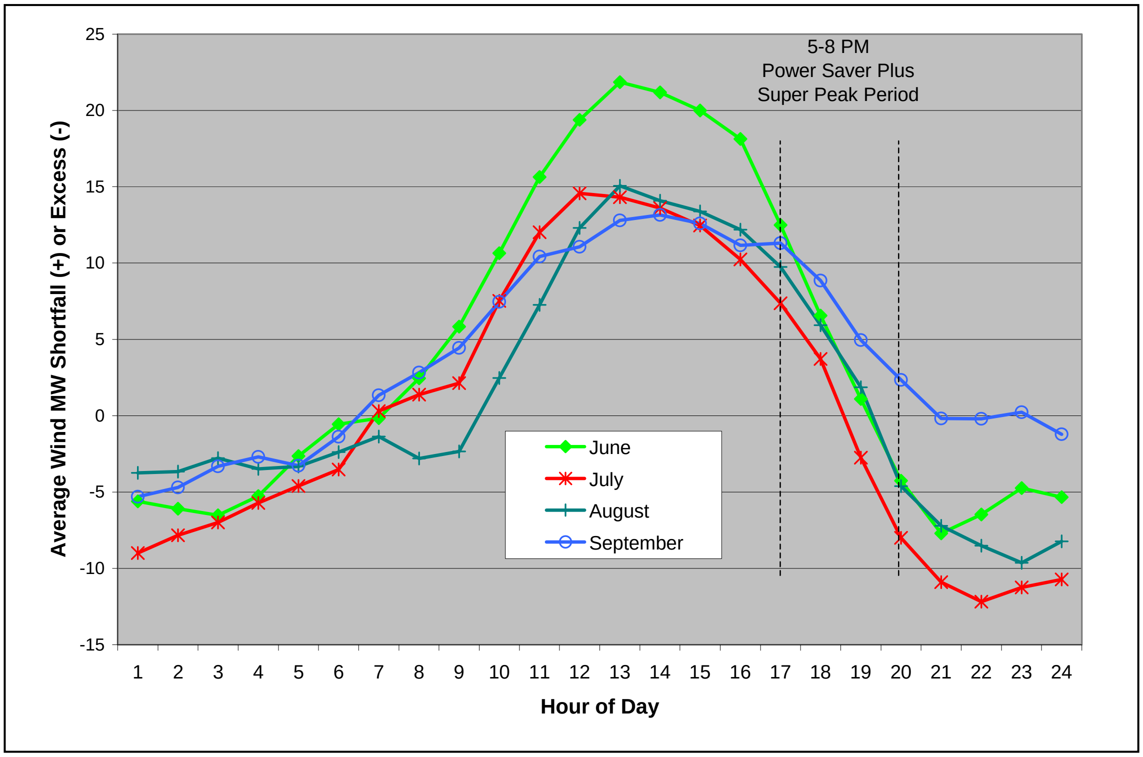

Figure 18: Daily Solano Wind Shortfall/Excess by Month (Photo Credit: Davis Energy Group)

Figure 19 plots full summer average indoor temperatures and cooling demand profiles for the three modes. The graph shows ACPC effectively moving much of the super peak demand to earlier mid-day hours; however, the higher overall consumption results in unfavorable homeowner economics under existing SMUD standard and pilot PSP TOU rate options. NBPC is much more effective at both reducing peak demand and energy use, and also shifting load to off-peak hours through the use of ventilation cooling.

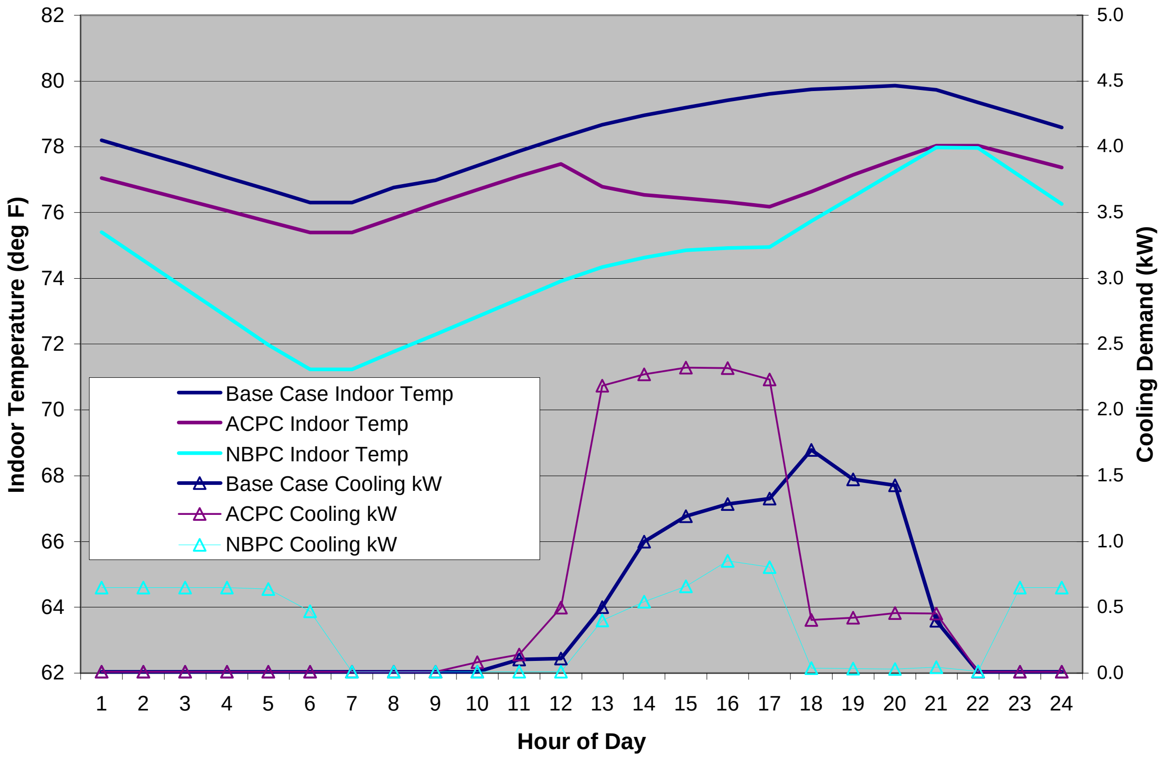

Figure 19: Average Indoor Temperatures and Cooling Demand Profiles by Mode

Photo Credit: Davis Energy Group

Since NBPC is the only potentially viable option under existing SMUD pilot PSP TOU rates, ACPC was dropped from further analysis. Figure 20 compares how the full summer wind shortfall/excess varies with time of day and how the NBPC vs. base case demand difference matches with the wind data. Results show a very favorable alignment of the NBPC strategy since excess wind capacity is typical during nighttime hours (during night ventilation operation). During mid-day periods when there is typically a wind shortfall, NBPC demonstrates a slight demand reduction. The NBPC demand reduction benefit is greatest during the super peak period when the projected wind shortfall is starting to decline. The hours with wind capacity shortfall were further analyzed. Of the 1,689 "shortfall" hours during the June through September period, 503 hours were found to have higher demand with conventional AC operation and 1,186 with the NBPC strategy. However, the average outdoor temperature associated with the shortfalls was 85°F for AC and 66°F for NBPC, clearly indicating that the pre-cooling strategy provides demand reduction when it is needed.

NBPC operation also facilitates the concept of direct utility load control on those days when demand reduction is needed due to wind shortfall. By using night ventilation on a daily basis, house interior mass will be at a lower indoor temperature than a conventional house. Efficient night ventilation pre-cooling coupled with a degree or two of air conditioner pre-cooling would be expected to provide sufficient buffer space to allow a one hour cycling control and maintain comfort during the 5 to 8 p.m. super-peak.

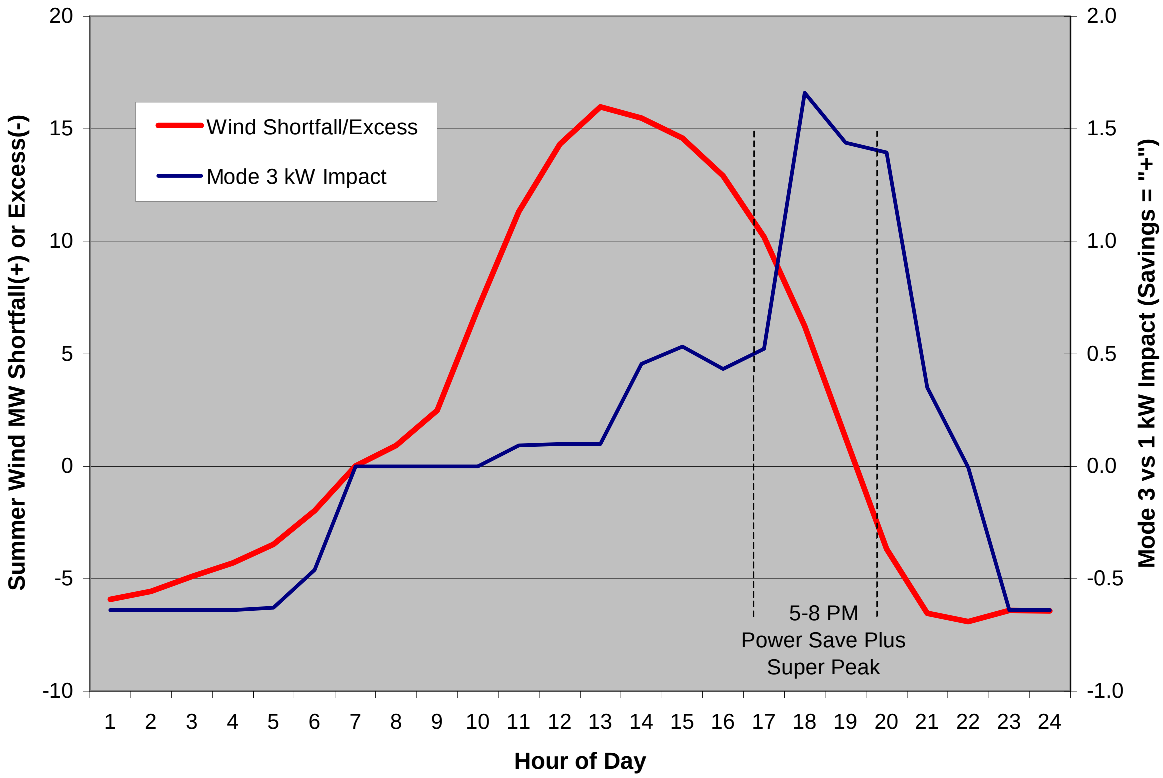

Figure 20: Full Summer Wind Shortfall Profile with NBPC Demand Impact

Photo Credit: Davis Energy Group

These projections suggest that the NBPC strategy is well-suited to supplement the SMUD Solano wind output, and when operationally coupled, mitigates the impacts of imprecise wind forecasting. The next big question is: How many homes are needed to provide avoided capacity to balance the 5 to 8 p.m. super-peak wind shortfall? On average for the full summer, the number of required homes during this three-hour period was found to vary from 8,800 to 10,000. The four hottest days during the June through September period showed that two of the hottest days did not have any wind shortfall. The remaining two days showed a need of 11,000 to 12,000 homes and 2,000 to 4,700 homes, respectively. Further evaluation, homeowner surveys, and field monitoring is recommended due to uncertainties related to assumed setpoints, performance under heat storm weather conditions, and other factors.

6.6 Summary of Project Outcomes

The SMUD Off-peak Over-cooling project was underway for approximately two and a half years, from mid-2005 through the end of 2007. During this time there was significant work underway on various projects that intersected or ran parallel to this study. Examples include the PIER-sponsored NightBreeze Development Project (resulting in a two-zone gas furnace NightBreeze control with air conditioner pre-cooling capability), the Intel research referenced in this study, ongoing work with industry leaders, utilities, and the Energy Commission related to PCTs, and research underway at UC Berkeley and other entities related to wireless systems. This project provides a contribution to the general research area of efficient advanced system control to reduce air conditioner on-peak energy consumption, while maintaining indoor comfort. ***The key project outcome validated by DOE2 modeling and field monitoring is that an advanced NightBreeze ventilation cooling system coupled with a noon to 5 p.m. pre-cooling period, can reduce SMUD super-peak (5 to 8 p.m.) cooling energy consumption by nearly 90 percent.*** This result warrants further study to demonstrate applicability to a broader sample of SMUD residential customers.

Additional key project outcomes include the following:

NightBreeze represents the best option for a short-term solution for a low cost control package that can cost-effectively provide pre-cooling. Although the current control needs minor refinements to avoid over-cooling on mild days, it can effectively serve as a pre-cooling control in efficient new homes. Ideally, a preferred future strategy is for the electric meter to serve as the gateway for the utility to communicate with the HVAC thermostat and other high electrical demand appliances, as well as providing timely feedback to homeowners. This communication could take the form of price signals as well as on/off control signals in the event of peak load emergencies.

DOE2 simulation of preferred pre-cooling strategies suggested that a five hour air conditioner pre-cooling interval prior to the SMUD 5 to 8 p.m. super-peak would offer the best economics for the homeowner and the greatest utility benefit. DOE2 projected results for the typical house suggest energy savings of 440 kWh/year (24 percent), super-peak cooling energy savings of 97 percent, and operating cost savings of $111 (21 percent) under the SMUD Power Save Plus rate.

2006 field monitoring of air conditioner and ventilation cooling plus air conditioner pre-cooling was inconclusive due to a shortened monitoring period, variable weather conditions, and operational problems. Monitoring in 2007 was subsequently added to bolster the 2006 field monitoring results. In 2007, a NightBreeze equipped home located in Folsom (east of Sacramento) resulted in successful data collection for the full summer period. Performance results in 2007 suggest that a combined NightBreeze and air conditioner pre-cooling strategy could effectively reduce super-peak cooling energy consumption (projected 88 percent reduction vs. base case), but overall cooling energy usage was projected to increase by 26 percent. The net impact to the homeowner under the SMUD PSP pilot rate was an estimated $9 per year increase in cooling costs ($158 vs $149). The 2007 results and projections are considered conservative since the NightBreeze system was undersized for the house and the installed cooling system was of insufficient capacity to provide pre-cooling on days when outdoor temperatures exceeded 100°F. Although 2007 field results were not as positive as the original DOE2 projections in terms of total cooling energy use, the field results present a strong case for further field studies.

Evaluation of wind generation data from a 102 MW SMUD Solano County wind farm suggest a good match with summer wind generation profiles since pre-cooling strategies utilize electrical energy when the resource is available and reduce consumption when the yield is low. A fleet of roughly 5,000 to 10,000 homes with air conditioner and ventilation pre-cooling are projected to be needed to offset the wind farm peak period shortfall.

Chapter 7: Conclusions and Recommendations

7.1 Conclusions

TASK 1: Identify potential pre-cooling technologies and control options that would facilitate optimized pre-cooling operation.

At this point in time it is difficult to project where technology and the marketplace will go. Ideally, a preferred future strategy is for the electric meter to serve as the gateway for the utility to communicate with the HVAC thermostat and other high electrical demand appliances, as well as provide timely feedback to homeowners. This communication could take the form of price signals as well as on/off control signals in the event of peak load emergencies.

The NightBreeze ventilation cooling system represents the best short-term solution for providing a low-cost control and hardware package that can cost-effectively provide ventilation and air conditioner pre-cooling. Although the current control needs minor refinements to avoid air conditioner mid-day over-cooling on mild days, it can effectively serve as a pre-cooling control in efficient new homes. The SmartVent control also offers the potential to serve as a viable pre-cooling control, although expected energy savings are likely lower since the system cannot realize savings associated with variable speed operation.

TASK 2: Analyze the options and identify a preferred optimal package.

Monitoring results in 2007 indicate that ventilation cooling combined with air conditioner pre-cooling clearly provides significant load-shifting benefit to SMUD. However, the current SMUD PSP pilot rate structure does not offer an incentive to the homeowner. Nevertheless, this strategy appears to be an effective near-term approach for SMUD to pursue. The NightBreeze control system allows some improvements over the SmartVent model in terms of reducing non-peak energy consumption. The performance of both systems would improve with some control modifications. Longer term pre-cooling strategies could feature one- or two-way communication, allowing the utility to either send price signals to the customer, or to send pre-cooling target temperatures based on upcoming weather events.

TASK 3: Complete computer simulations of the preferred design to estimate performance.

DOE2 simulations suggest a noon to 5 p.m. air conditioner pre-cooling period provides the greatest benefit to both the homeowner and the electric utility. DOE2 results for the typical house modeled project energy savings of 440 kWh/year (24 percent), 5 to 8 p.m. super-peak cooling energy savings of 97 percent, and operating cost savings of $111 (21 percent) under the SMUD Power Saver Plus rate.

TASK 4: Perform field monitoring of the preferred design to assess real world performance, operating characteristics, and suggested improvements.

Although 2006 field monitoring of air conditioner and ventilation cooling plus air conditioner was inconclusive, 2007 monitoring at a NightBreeze equipped home east of Sacramento provided useful data on pre-cooling performance. Extrapolating the 2007 field results to the full summer weather indicates that a combined NightBreeze plus air conditioner pre-cooling strategy would reduce super-peak cooling energy consumption 88 percent vs. base case; however, full season cooling energy usage was projected to increase by 26 percent. The super peak savings results (consistent with the DOE2 projections) suggest that it is possible to virtually eliminate on-peak cooling energy usage in a thermally efficient home; however, overall cooling energy usage for this house was considerably higher than modeled (26 percent increase vs. DOE2 projected 25 percent savings). The net projected added homeowner cost under the SMUD PSP pilot rate was an estimated $9 per year increase. The 2007 results and projections are felt to be conservative since the NightBreeze system was undersized for the house and the installed cooling system was of insufficient capacity to provide pre-cooling on days when outdoor temperatures exceeded 100°F.

TASK 5: Evaluate potential synergies between SMUD's 102 MW Solano wind plant production profile with projected demand profiles for both conventional air conditioned homes and also pre-cooled homes.

Typical Solano wind farm production profiles demonstrate a mid-day valley with production at less than 20 percent of nominal output during the 11 a.m. to 4 p.m. time window when typical Sacramento cooling demand starts to build. Peak wind production occurs from 9 p.m. to 3 a.m. Although pre-cooling under the SMUD PSP rate scenario will require air conditioner operation[32] during the period when wind output is lowest, 2007 monitoring suggests that 88 percent of the super-peak consumption can be avoided, allowing valuable peak generation resources to be applied elsewhere.

7.2 Commercialization Potential

This project did not require a Production Readiness Plan. The project did, however, demonstrate a pre-cooling strategy that does offer near-term potential for customers with NightBreeze or SmartVent ventilation cooling systems. The proposed strategy was shown to provide significant utility benefit in terms of shifting cooling energy consumption from the 5 to 8 p.m. super-peak period to on- and off-peak periods. Future control enhancements could improve the observed over-cooling that is currently resulting in no financial incentives to homeowners under the SMUD pilot PSP rate.

7.3 Recommendations

The results from this study are promising enough to encourage further efforts to better understand pre-cooling benefits on a statistically valid sample of SMUD customers. Specific activities that should be pursued include:

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32. Continuous operation on the hottest days.

1. Pursue additional detailed field testing in 2008 with SmartVent systems and NightBreeze systems (target airflow of 0.6 cfm/ft^2 of floor area) coupled with conventionally sized, air-cooled air conditioners. The 2007 monitoring was beneficial, but slightly atypical of new SMUD production housing.

2. Complete energy use monitoring on a large sample of new (high cooling performance) homes. Thirty to 50 homes could be monitored for cooling energy consumption in both base case and ventilation cooling plus pre-cooling modes of operation. An ideal candidate for inclusion in such program would be SMUD SolarSmart home builders. These homes incorporate many of the cooling energy efficiency measures that are needed for a successful pre-cooling strategy.

3. Work with ventilation cooling product vendors to enhance pre-cooling capabilities to minimize air conditioner over-cooling on milder days. Enhanced performance could be achieved by adding an indirect evaporative cooling module applied to the outside air intake of a SmartVent or NightBreeze ventilation cooling system, but this effort will require further product development.

4. Combine the electrical load patterns generated in the 2007 monitoring study with SMUD hourly marginal cost data to determine if the load shifting benefits are fairly reflected in the SMUD PSP pilot rate.

5. Survey a broad sample of SMUD homeowners to determine comfort preferences. An important consideration is determining what percentage of homeowners are amenable to tolerating indoor temperature fluctuations of about 10°F during the course of a day if they save "X" percent on their electric bill. Understanding thermostat schedules, thermostat control patterns, and the level of incentives necessary to change behavior is an important part of assessing wide scale pre-cooling acceptance.

6. Encourage similar pre-cooling monitoring studies with other California utilities. Other utilities may have peak periods occurring at different times during the day, allowing for potentially greater efficiency advantages since air conditioner pre-cooling would occur earlier in the day.

7. A broader pilot program collecting data from a statistically valid sample of homes would provide a better understanding of how the wind resource meshes with a ventilation cooling/air conditioner pre-cooling strategy.

8. Support efforts to review and update standard hourly weather files used for DOE2 and other hourly simulation models to ensure heat storm events are properly included.

7.4 Benefits to California

The immediate benefits of residential pre-cooling lies in addressing statewide peak demand issues. Shifting peak load to shoulder or off-peak periods increases the reliability of the generation, transmission, and distribution infrastructure. Additionally, shedding peak load increases transmission efficiencies since transmission system peak losses are highest when system demand is highest. Also, reducing super peak demand will reduce the state's reliance on gas generation peaker units resulting in beneficial air quality impacts. Improvements in night ventilation performance (or augmented night ventilation systems) coupled with improved control of air conditioner pre-cooling (avoiding unnecessary cooling) could eliminate the current cooling energy penalty of approximately 25 percent.

Monitoring results in 2007 suggest that SMUD super-peak period energy savings of close to 90 percent were achieved with homeowners tolerating indoor temperatures up to 80˚F. Theoretically, demand savings approaching this level can be achieved if homeowner comfort is marginally compromised on the peak demand days. Alternatively, demand savings of about 50 percent are easily achievable without compromising indoor comfort by either cycling the air conditioner off for most of the super-peak period or operating a two-speed condensing unit only at low speed. With typical SMUD diversified residential cooling demand of 3 kW, a conservative 50 percent reduction would amount to demand savings of 1.5 kW per household.

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GLOSSARY

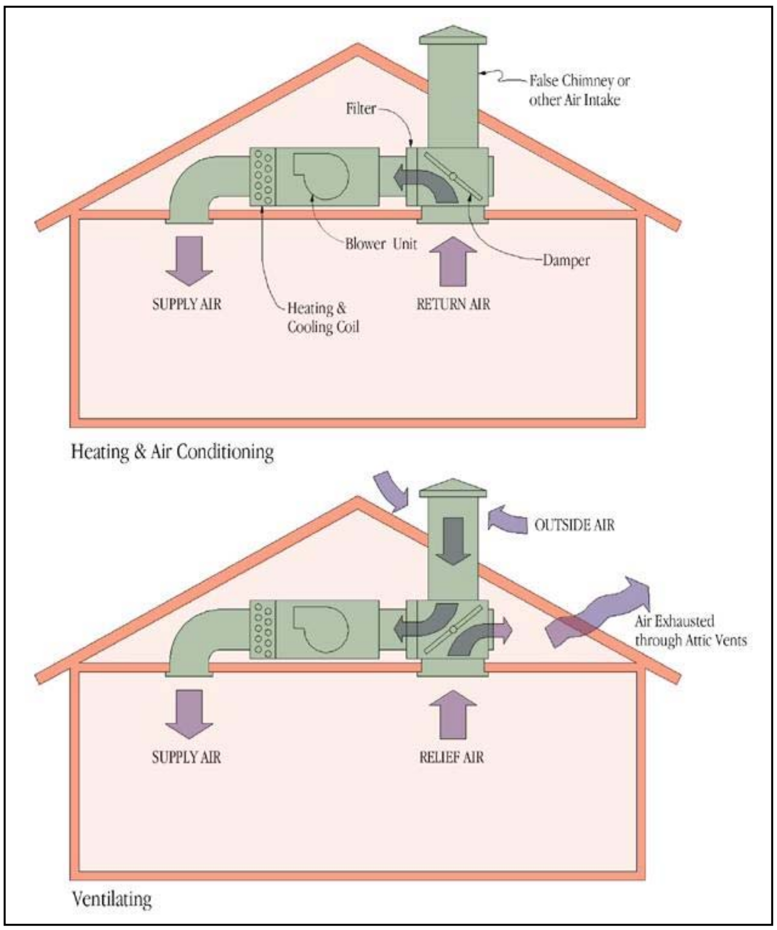
Acronym	Description
AC	Air conditioner
ACPC	Air conditioner pre-cooling
AFUE	Annual Fuel Utilization Efficiency
AMI	Advanced Metering Infrastructure
CDD	Cooling degree days
CEC	California Energy Commission
cfm	Cubic feet per minute
DEG	Davis Energy Group
DR	Demand Response
DSL	Digital subscriber line
ECM	Electronically commutated motor
EER	Energy Efficiency Ratio
hp	Horsepower
HVAC	Heating, Ventilation, and Air Conditioning
IOU	Investor owned utilities
kW	Kilowatt
LAN	Local area network
LCD	Liquid crystal display
LED	Light emitting diode
MW	MegaWatt
NB	NightBreeze
NBPC	NightBreeze with air conditioner pre-cooling
PIER	Public Interest Energy Research
PC	Pre-cooling

PCT	Programmable communicating thermostats
PG&E	Pacific Gas and Electric
PLC	Power line carrier
PSP	Power Save Plus
RF	Radio frequency
RCS	Residential Control Systems
RH	Relative humidity
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
SMUD	Sacramento Municipal Utility District
TOU	Time of Use
UC	University of California
USB	Universal serial bus
UPB	Universal powerline bus
VHF	Very high frequency
WAN	Wide area network

Appendix A:
Comparison of SmartVent and NightBreeze Ventilation Systems

Both SmartVent and NightBreeze systems provide night ventilation cooling, but there are some significant differences in capabilities and performance. The key components of each system are a damper box (located between the system return(s) and the air handler or furnace), outdoor air duct, outdoor temperature sensor, and controls. Figure A1 shows a schematic of system operation in standard heating or cooling mode (top figure) and in ventilation cooling mode (bottom figure). Currently, several thousand SmartVent units are being sold annually while the emerging technology of the NightBreeze system is just starting to enter the market.

Figure A1: Ventilation Cooling System Schematics



A comparison of key features of the two system types can found in Table A1 below. The NightBreeze unit offers a greater ability to customize operation and optimize the efficiency of the night ventilation. Since the nightly vent target varies upward as conditions are milder, the system self-compensates to avoid over-cooling on mild days. SmartVent users may be predisposed to setting a higher ventilation target to avoid the over-cooling problem.

Table A1: Comparison of SmartVent and NightBreeze Capabilities

	SmartVent	**NightBreeze**
System type	Any type of furnace	Variable speed hot water air handler or variable speed furnace
Ventilation air flow	Fixed at manual fan speed	Varies with expected cooling demand (higher on hot days, lower on mild days). Can vary from 10-100% of maximum with significant energy benefits at reduced fan speed.
Low limit temperature*	Fixed at the owner's setting	Owner sets low limit target, but daily target varies with expected cooling demand (lower target on hot days, higher target on mild days)
Winter fresh air ventilation option	No	Yes. Ventilation rate can be adjusted to meet ASHRAE 62.2 requirements.
Continuous feedback on the consequences of cooling temperature settings	None	Control logic predicts what the indoor temperature range will be based on the temperature settings. Thermostat display indicates if the air conditioner is likely to run the next day.
Self-diagnostics	No	Yes. Detects damper failure or heating/air conditioning failure and activates 'Service' light
Zoning capability	Up to 4 zones	Up to 2 zones

* The indoor temperature at which ventilation is terminated

Projected energy and demand impacts of the two systems (relative to a house where windows are not used for nighttime ventilation) are shown in Table A2 below. These results were generated with DOE2 for the 16 California climate zones for a 3,080 sq. ft. Title 24 compliant home. NightBreeze demonstrates significantly higher energy savings due to variable speed control capability and optimized target temperature calculations. Two SmartVent datasets are shown: the original and the "NB", which incorporates the NightBreeze daily target calculation. The latter shows improved performance, but the lack of variable speed capability is still a significant performance handicap. Demand savings for the two systems are comparable since on a peak day both systems would operate at full fan speed.

Table A2: DOE2 Projected Energy and Demand Savings (No ventilation base case)

Climate Zone	Annual Cooling Energy Savings			Peak Cooling Demand Savings		
	NightBreeze	SmartVent (NB)	SmartVent Original	NightBreeze	SmartVent (NB)	SmartVent Original
CZ 01	-71%	-12%	-25%	-13%	-	-
CZ 02	51%	-13%	-17%	50%	54%	54%
CZ 03	-78%	-212%	-328%	68%	71%	71%
CZ 04	55%	-42%	-56%	74%	76%	76%
CZ 05	-132%	-245%	-347%	55%	60%	60%
CZ 06	32%	-126%	-218%	66%	76%	72%
CZ 07	51%	-77%	-146%	41%	56%	79%
CZ 08	52%	-27%	-52%	52%	54%	56%
CZ 09	47%	-10%	-22%	39%	42%	42%
CZ 10	39%	2%	-2%	42%	39%	39%
CZ 11	38%	8%	6%	37%	33%	33%
CZ 12	51%	3%	1%	36%	32%	32%
CZ 13	23%	3%	1%	26%	22%	22%
CZ 14	23%	2%	0%	36%	32%	32%
CZ 15	5%	-6%	-7%	30%	27%	27%
CZ 16	54%	-3%	-5%	50%	48%	48%

Appendix B:
Intel Evaluation Report

Energy Management in the Digital Home

By Michael Breton

Folsom Innovation Centre

Mike Breton has been with Intel 16 years and is now on a 12 month assignment focusing on digital home, Controls, and Automation for the ISTG Innovation Centre. Most recently he focused on Intel's Messaging Services, coordinating Solutions Architectures and managing the Messaging Engineering team. Prior to that role he was a senior engineer for NOS Technology Integration (NTI) focusing on enterprise Windows server technology. Mike is interested in just about any area of technology. His hobbies include

First Published: 07/27/2005

Updated: 10/17/2005

Home Controls, Automation and integration projects.

Overview

In February 2005, the Intel Folsom Innovation Centre approached the Sacramento Municipal Utilities District (SMUD) researching Smart Meters (power meters that could be read via PC in the home). That early engagement lead to a joint SMUD / Intel project to "proof of concept" or "prototype" three energy saving scenarios to be deployed in Intel employee homes in Folsom. SMUD had existing plans to study Off-Peak Pre-Cooling, which remains the primary focus area and has since secured funding for their research. SMUD has contracted with Davis Energy Group to lead the study and document the results. The three Intel homes will be included in the study and load (HVAC) control solutions will be driven by Intel processor-based PCs.

Off-Peak Pre-Cooling Concept Defined

Over-Cooling a home prior to the hottest part of the day, and the peak energy period is easier and more cost effective. A "smart home" would determine the forecasted temperate and based on the desired set point temperature in the home, say 78 degrees, would pre-cool or over-cool in the morning to a calculated value, say 72 degrees. The cooling system would then turn off when the peak energy period begins, say 12-1pm and allow the home to naturally float up to the ultimately desired set point.

Primary Goal (SMUD)

Validate Off-Peak Over-Cooling reduces max peak load while providing consumer comfort. (Optimized for Utility benefit)

Secondary Goal (SMUD)

Use of Time of Use (TOU) rates results in savings to consumer.

Proof of Concept / Prototype Goals

- Use the 3 Intel homes as data collection points
- Use an Intel processor-based PC and Intel Innovation Centre control experience to help create concept
- Use the 3 Intel homes as a test case for pre-cooling algorithms
- Understand capabilities and limitations of retro fit

Other Project Scenarios

Although Pre-Cooling was the utility's and their consultants primary focus area, there were two other scenarios we wanted to demonstrate how a Intel processor-based pc could add value.

Usage Awareness

Provide access to near real time energy consumption and costs in the home via Intel processor-based PC and/or Intel processor-based Media Center PC. Awareness Inspires Action - Recent studies have shown a 10 percent-15 percent voluntary reduction of Energy usage when occupants are aware of usage and costs.

On Utility Demand Load Shedding

Allow for the Utility to request the "Smart Home" to shed some of its energy load on demand for a period of time, while ensuring a positive experience for the homeowner via knowledge and flexibility.

Value Targets

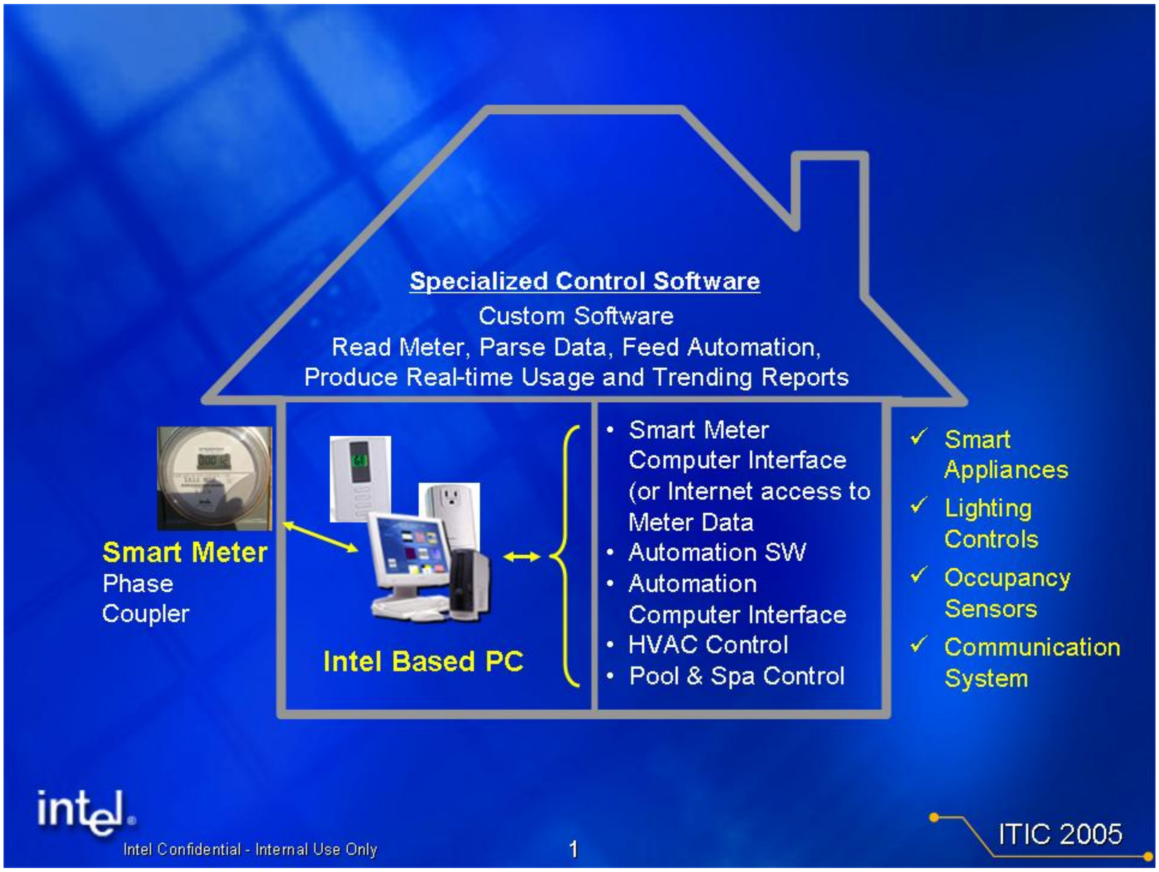
- Utilities save cost of new generation and transmission facilities
- Consumers save on utility bills
- Drives the need for an Intel processor-based PC in the home
- Drives expansion opportunities and additional use cases for the Entertainment platform in the home

Pilot Homes in Folsom, CA

Home	Size	Floors	Age	Exterior	Roofing	West Facing Windows	Shading	HVAC Units	HVAC Zones	Norm Point	Other Cooling	Notes
1	2460	2	6.5	Stucco	Tile	2 3 by 4 and 2 1 by 1	None	1	2	78	6 Ceiling Fans and Whole House Fan (manual)	East facing windows bring in morning heat could be an issue

2	3025	2	15	Stucco	Shake	3 3ft by 4ft	Many Large Trees	2	1 each	80	Whole House Fan (manual)	
3	2350	1	5	Stucco	Tile	West 100% shaded by 2 story neighbor. Southwest has 6 windows – 1 3ft by 4ft, 1 5ft by 8ft, 3 2ft by 4ft, and 1 18in by 3ft	None aside from previously mentioned neighbor	1	1	Night = 76 / Day = 80	5 Ceiling Fans	

Conceptual Architecture



Reference Architecture

Although a single overall platform and associated ecosystem will be used to support the three primary scenarios; Pre-Cool, On Demand Load Shedding, and Awareness, it is important to note that not all aspects are necessary for all scenarios. The central platform will consist of a computer connected to the home's primary entertainment display (TV) for viewing purposes. Home Automation and other specialized software will be installed to collect, normalize, storage, and display from temperature sensing devices, as well as a whole house energy meter. Interfaces will include radio frequency reading of the whole house energy meter and a command and control interface for HVAC. Internet access will also be used to transfer data to project parents as well as to provide remote access to data and control systems. Wireless and powerline technologies would be used for meter and control system communications.

Solution Architectures

Computer Hardware

A HP Entertainment Center (model z555) platform was used to drive the entire system and in all scenarios. This system is a Intel Processor based PC running Windows XP Media Center Edition and was connected to the primary entertainment viewing device (TV) in each home. The system can be used to drive the 10' Experience in the home managing Entertainment aspects such as Television, personal video recording, digital music, and digital videos. Although those capabilities exist, they are out of scope for this project and the system was primary used to show how Energy Management could be added to the existing platform and how Energy Awareness could be viewed via the 10' Experience.

Smart Meter and Reader

Itron provided electronic meters and readers for the project. The meters replaced the existing analog meters attached to each home's electrical panel and are of a type now commonly used in new homes in our area. The specific type of meter we used broadcasts its reading every 2-3 minutes and can be picked up via a special reader attached the PC in the home. The reader connects to the PC via a standard USB port and is accessed via terminal emulation software.

Computer Interface for Command & Control

In the scope of this project, only one device type was needed in the Command & Control space, HVAC. Originally, we choose to install thermostats that could be controlled over the homes existing electrical wiring, or powerline using the Universal Powerline Bus protocol. Unfortunately, devices using this protocol were not currently available so we used thermostats based on the x10 powerline protocol and had to deal with the typical x10 reliability issues. Two of the test homes already had x10 based systems with existing phase couplers and filters. The 3rd home experienced x10 communication issues with the new thermostats until a phase coupler and two filters were installed. Again, a UPB based system would solve this issue. For inside the home, we used

the TS40 thermostat from Residential Control systems. This thermostat provides local display and control as well as access and management via x10 from the home automation system. Another thermostat from RCS, also using the x10 protocol, was used to record outdoor temperature. On the computer side, a USB based x10 interface from Smarthome was used. The SmartLinc USB allows home automation software to communicate with x10 devices over the powerline.

<u>Software</u>

Several commercial and custom software packages were used to build out the entire system.

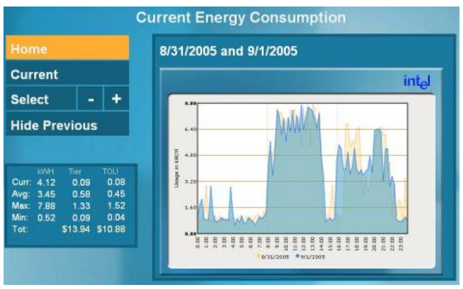
- HAL2000 from Home Automated Living was used to provide the core home automation solution. This system provides voice, web, pocketpc, touch screen and Media Center interfaces into all aspects of home control. In the case of this project, it was used to record temperate data from all thermostats in the home, including outside temperate, as well as to control the set points and modes of the cooling system, and was specifically used for implementation of the pre-cooling schedules in the home. This system will be referred to as "HAL" in the remainder of this document.
- To gather data, a custom application was write to log temperature data from the thermostats in the home every 15 minutes. HAL2000 could have been used to perform this logging but a bug in the software effected reliability and could not be fixed in time so the issue was worked around via the custom code. Each thermostat's data was written to a separate log file. Also a special terminal emulation software package from Itron was used to communicate with the meter reader and log the meter reads to a text file. This application also date and time stamped the meter reads as they were written to the text file.
- For the On Utility Demand Load Shedding scenario, a custom perl application using freeware components and a freeware HAL interface to change the status of a flag was used to demonstrate how HAL could "watch" a utility's website for critical load condition notification and then take load shedding action.
- In the Awareness scenario, the data collected (temperatures and whole house energy consumption) was normalized and feed in to a custom SQL database with stored procedures running on the PC in each home via a custom windows scripting application. SQL services were provided via MSDE instances. Additionally, custom web pages were developed for display within Media Center using the Media Center 2005 SDK and a 3rd party XML based Flash charting system (FusionCharts) to create the "My Energy" portal providing current and historical views in to the homes energy consumption, cost, and temperatures. These web pages were hosted locally via Microsoft Internet Information Services.

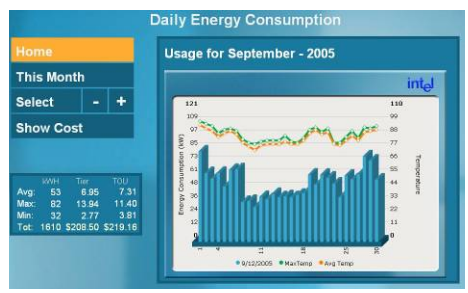
Tested Scenarios & Results

Not all three scenarios were included in all three test homes. Awareness, or the "My Energy" system, was included and used in all three homes. Pre-cooling was only tested in 2 of the 3 homes as one home did not need cooling enough to warrant any special use. Lastly, the On Demand Utility Load Shedding capability was created and demonstrated as a technology possibility in a showcase area and in one home but not actually implemented.

<u>My Energy</u>

The goal of the My Energy scenarios was to demonstrate how an Intel processor-based PC could be used to provide whole house energy consumption and costs to the homeowner via their primary entertainment system (television). Using the smart meter, reader, and customer software previously mentioned, we were successfully able to create such as system and run it in 3 homes without issue for 2+ months. The participants enjoyed having access to the data real time and other viewers expressed similar interest and in fact asked how they too could get systems like this installed in their homes. Different views in to the homes energy consumption were created and included: Current Usage in 15 minute increments, Hourly Usage, Usage for the week, month, and year. Each of these views also included kilowatt and cost information as well as inside and outside temperate. During the hottest part of the pilot, energy usage (air conditioning) tracked very closely to outside temperature. Additionally, the system included on screen Energy Saving tips and most recently added was a view for the billing cycle, which includes predictive technology automatically filling in the remaining days of the month to estimate your energy usage and total bill. This allows the home owner to become proactive in their energy savings. It is interesting to note that the My Energy system also provided an excellent visual feedback as to the effectiveness of the pre-cooling scenario. Real time access to the My Energy at the 3 pilot homes can be access via the following links:





House 1

http://bretonhome.dynu.com:8282/

House 2

http://faecasmf1.dyndns.org:8383/

House 3

http://totallyishamcom.dyndns.org/

It is important to note that the My Energy web pages were designed to be view on Media Center and although you can view them from a web browser, there are a couple of requirements. My Energy will only work with Microsoft Internet Explorer. Also, to full screen mode must be used (press F11) after bringing up the 1st page.

Utility On Demand Load Shedding

Power generation is expensive and in some locations demand is extremely variable. For example, in California, additional demand is needed during peak days in the summer months when "Heat Storms" hit. This demand is almost 100 percent driven by increased use of Air Conditioning. Increasing capacity is extremely expensive especially since it is only needed during a relatively short period. Given sufficient participation, On Demand Load Shedding could solve this issue. The utility would publish (on the internet) a request to shed load. An Intel processor-based PC based Automation system in the digital home would periodically check and based on the utilities demand notice, would notify the homeowner (email, SMS message to their cell phone, or voice in the home) that it is responding to the utilities request and then "up-tick" the home's thermostat by 2-4 degrees. The homeowner could override if desired. When the demand period has ended, the automation system would set the thermostat back to its normal set point. Participation in the program would result in lower energy costs for the consumer. Again, this capability was created and demonstrated as a technology possibility in a showcase area and in one home but not actually implemented.

Pre-Cooling

It is unfortunate that although this was the primary focus area of the utilities project, it was also the area affected most by the late start of the project. Once all the systems were in place the ready to collect data and manage the homes cooling system, we were left with only about 4 weeks of warm weather. After cooling a baseline before and after, we were only able to perform pre-cooling studied for about 2 weeks. That said, we were able to provide sufficient data to Davis Energy Group to perform computer simulations and conclude some of our own initial results.

On 8/24/2005 a "Static" precooling test was conducted at the one of the homes. The Intel Processor based PC providing home controls and automation managed the upstairs and downstairs thermostats to predefined values at predetermined times. The following schedule was used:

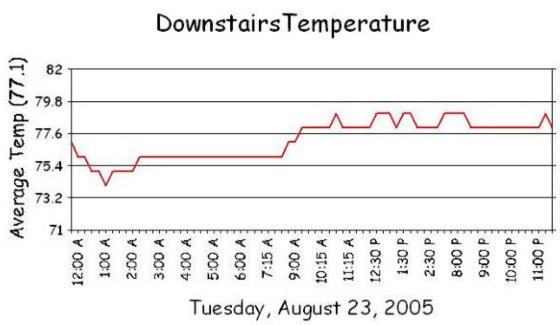
8am - set both thermostats to 73 degrees
2pm - set upstairs to 85 degrees & downstairs 78 degrees

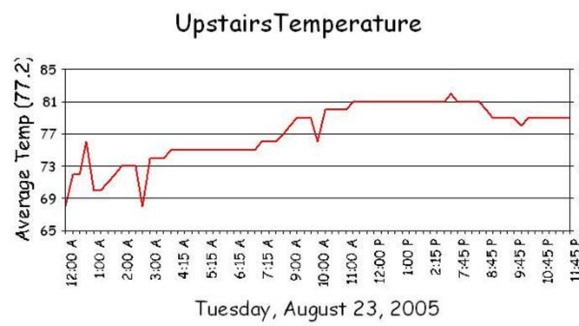
8pm - set upstairs to 78 degrees

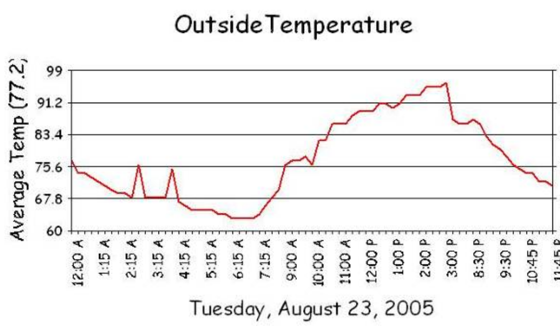
The data below provides a two day, before & after, comparison.

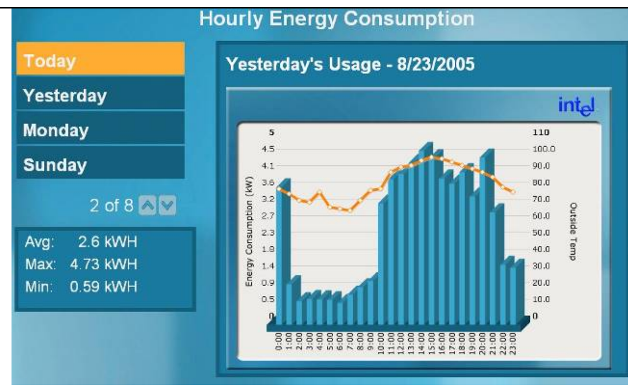
(larger charts available upon request)

08/23/05 – No Precooling (Day 1)

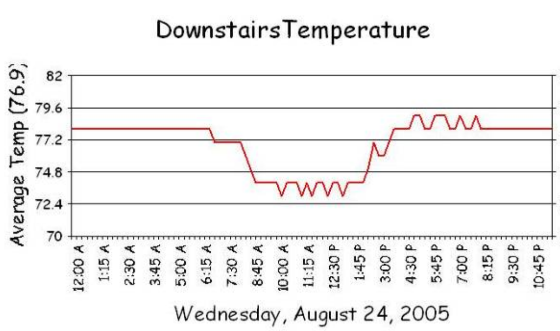


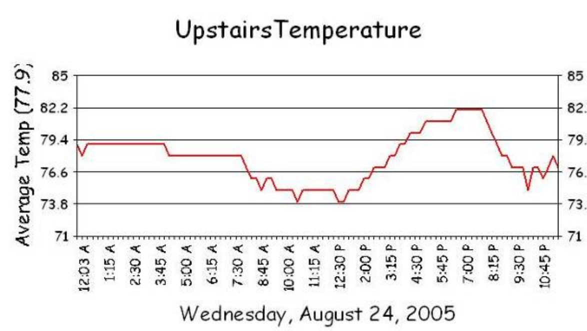


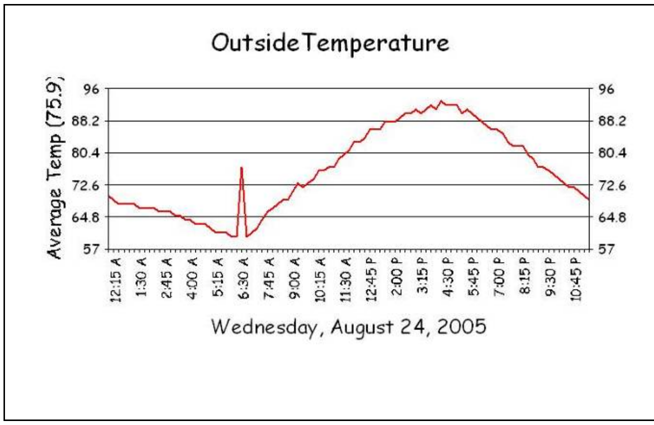


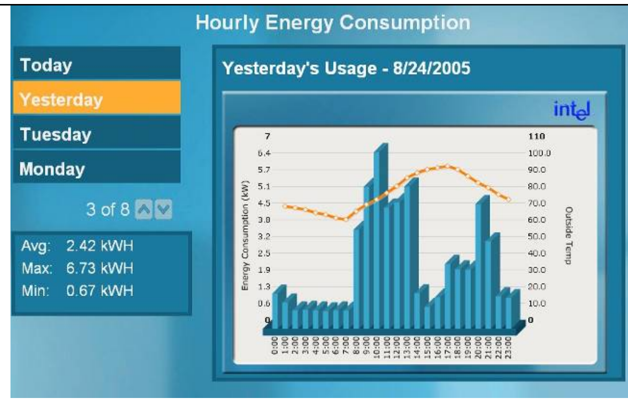


08/24/05 – Precooling Enabled (Day 2)



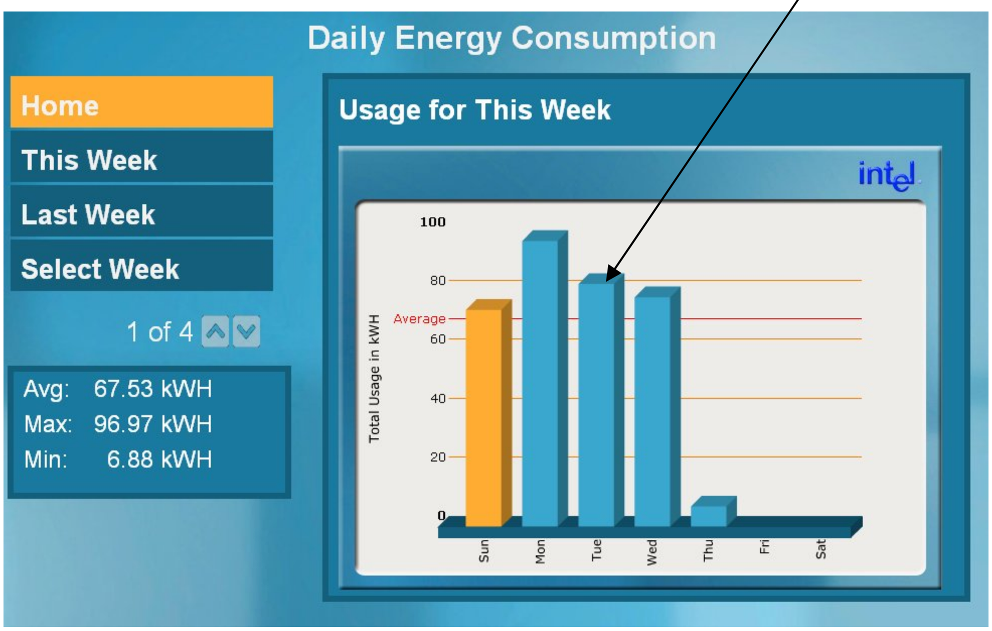




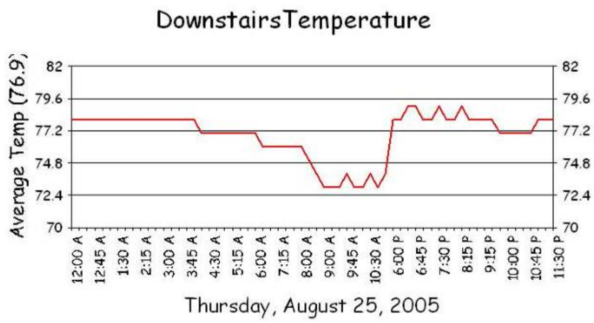


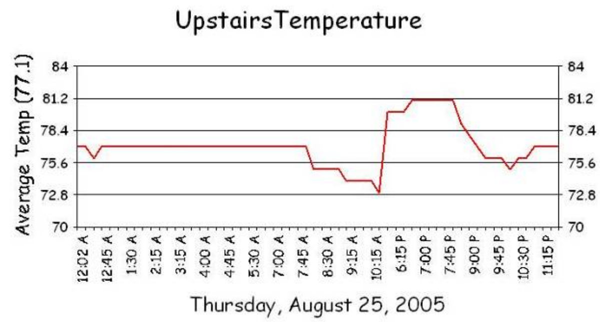
Daily Totals

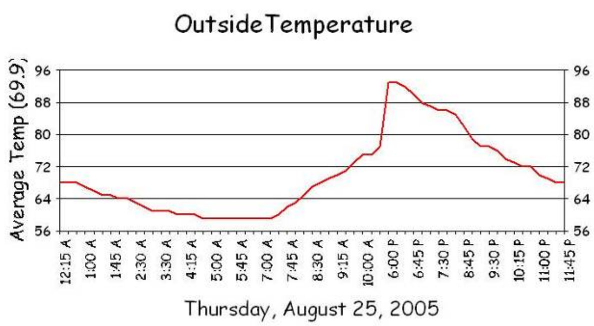
Note: Precooling resulted in "less" consumption (slightly cooler day)

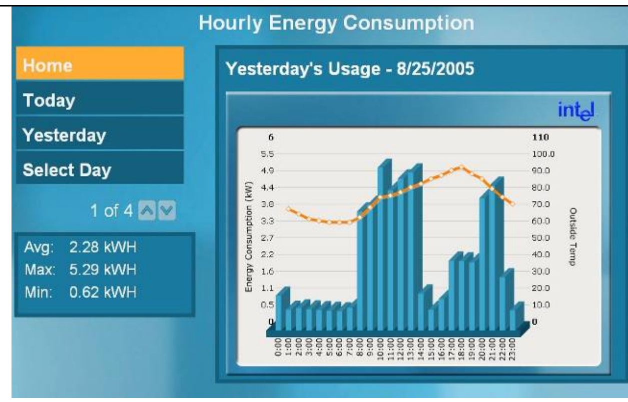


08/25/05 – Precooling Enabled (Day 3)



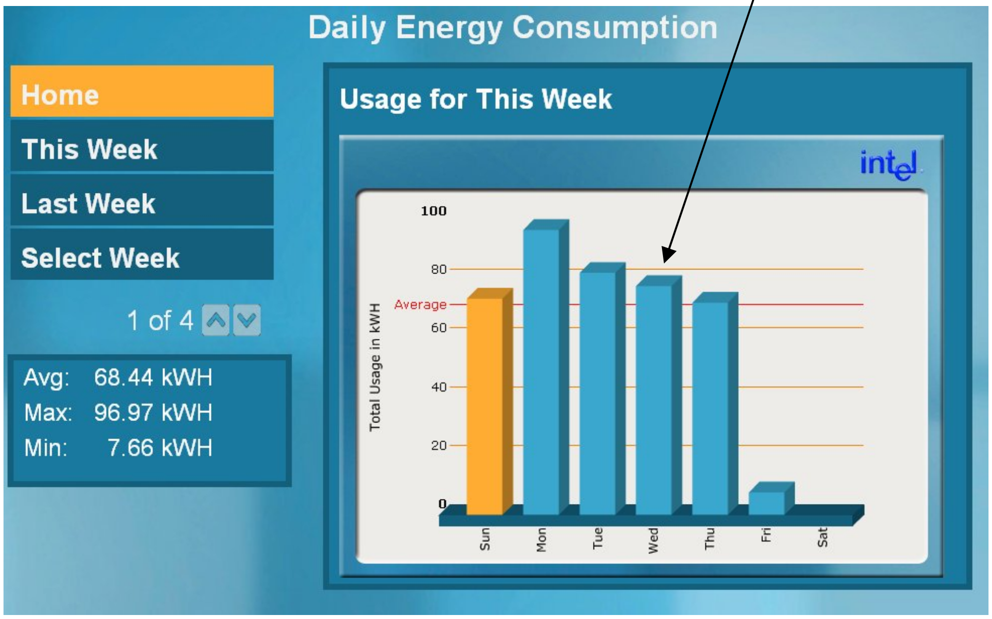






Daily Totals

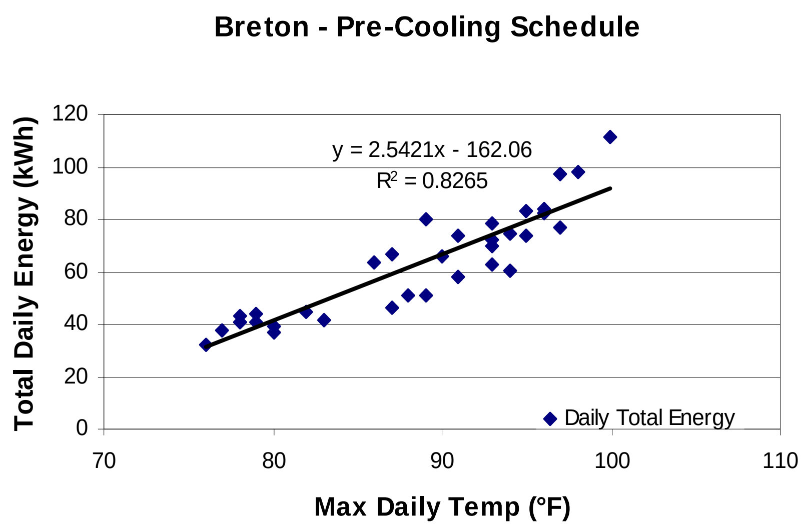
Note: Precooling continues to result in "less" consumption (slightly cooler day)

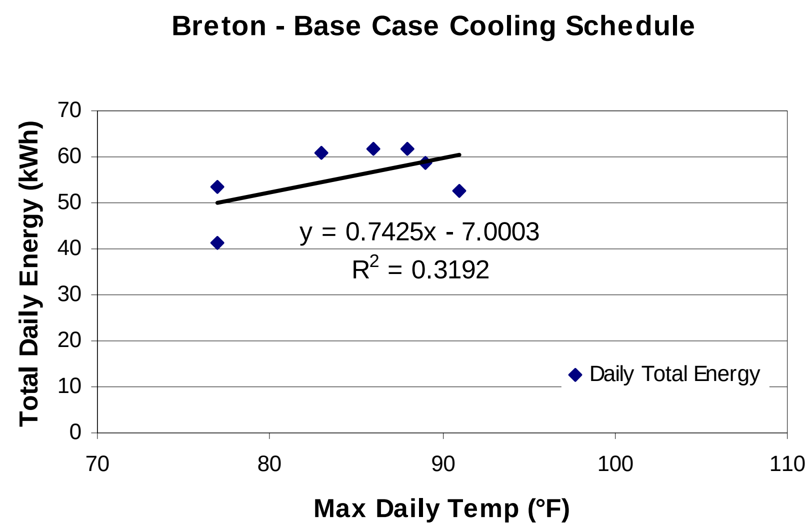


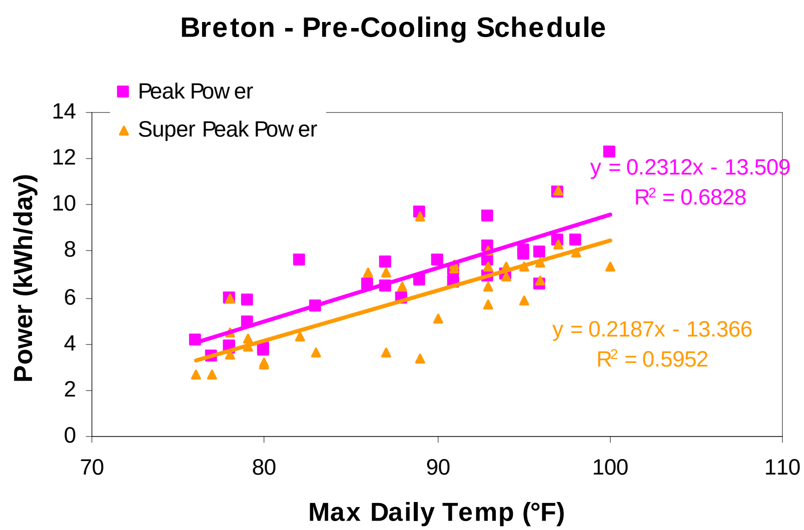
A similar static pre-cooling test was also performing at one of the other homes.

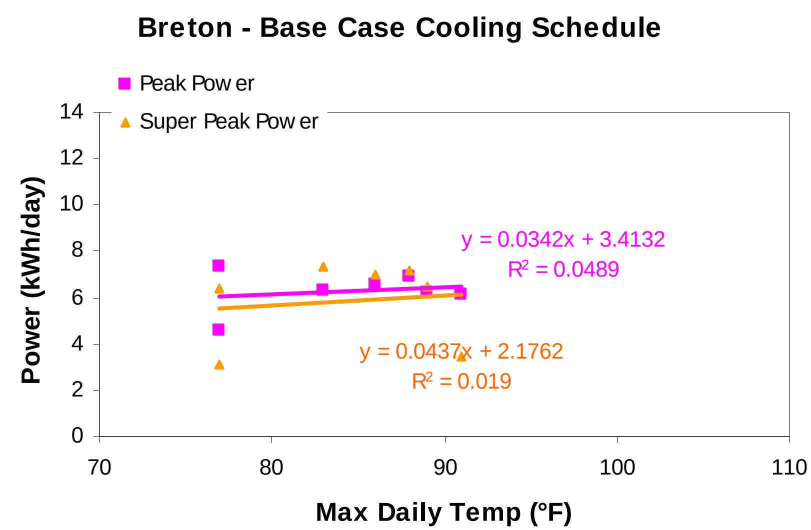
At a very high level, it does appear that pre-cooling, even in an older retrofitted home without any automatic nighttime cooling system, and assist the home in maintain a level of comfort through the super peak period without running the air conditioner.

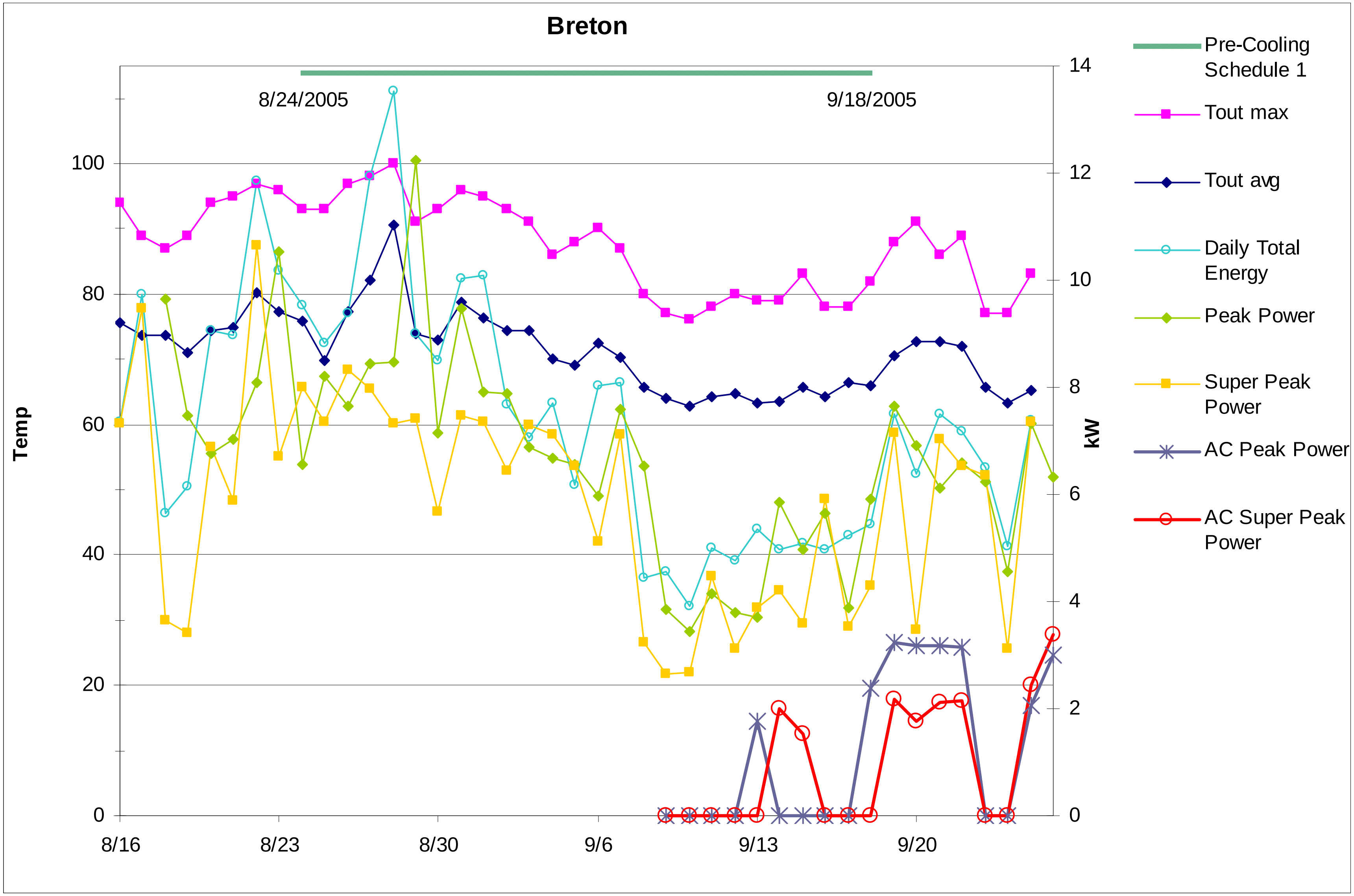
Detailed pre-cooling results including lab simulations will be made available when Davis Energy Group completes their mid project report expected late October to mid November 2005. The following are some early pre-cooling summaries of their data collected in one home.

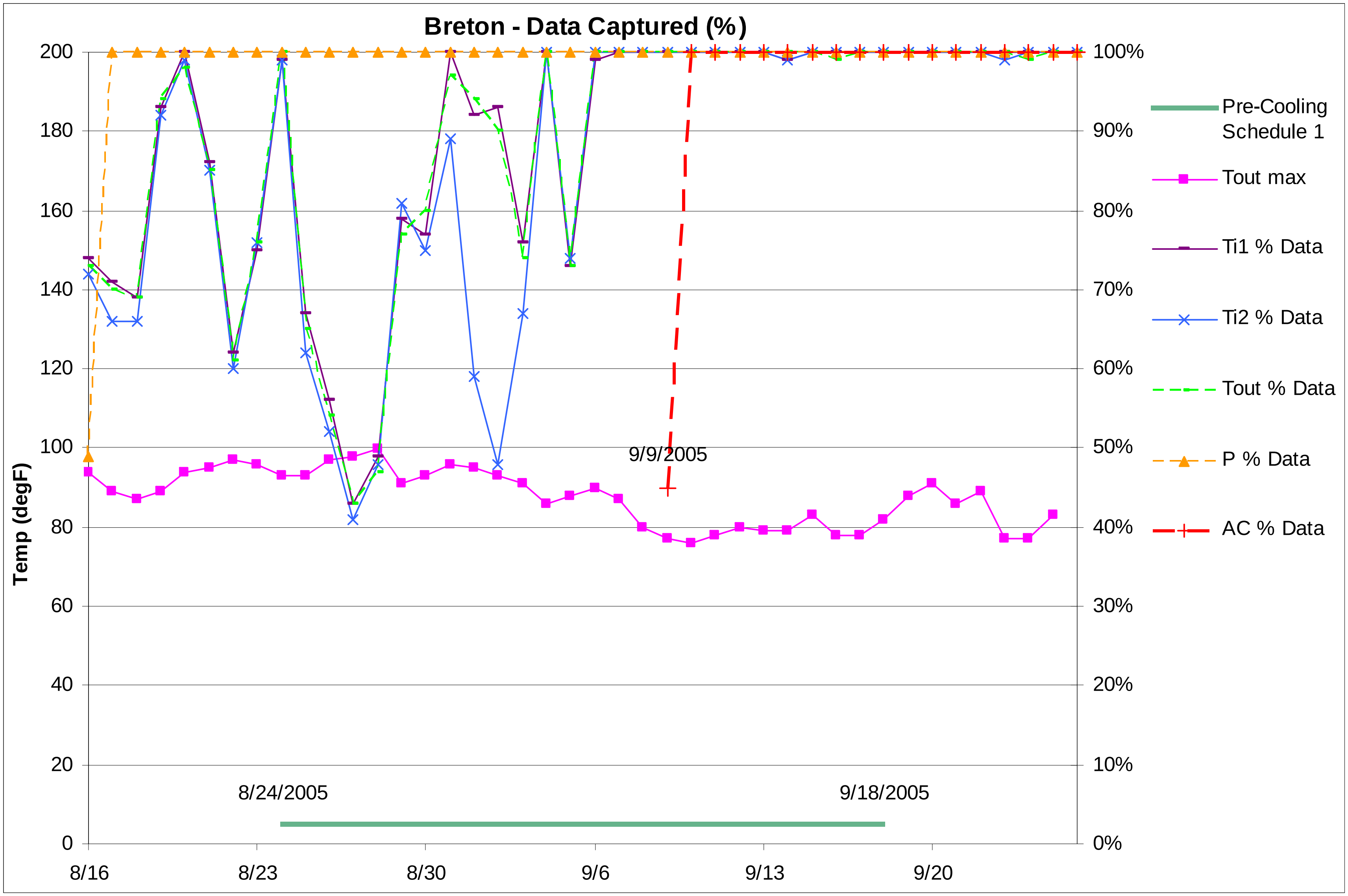

Breton - Pre-Cooling Schedule
Total Daily Energy (kWh)
Max Daily Temp (°F)
y = 2.5421x - 162.06
R² = 0.8265
Daily Total Energy
0
20
40
60
80
100
120
70
80
90
100
110


Breton - Base Case Cooling Schedule
Total Daily Energy (kWh)
Max Daily Temp (°F)
y = 0.7425x - 7.0003
R² = 0.3192
Daily Total Energy
0
10
20
30
40
50
60
70
70
80
90
100
110


Breton - Pre-Cooling Schedule
Peak Power
Super Peak Power
Power (kWh/day)
Max Daily Temp (°F)
y = 0.2312x - 13.509
R² = 0.6828
y = 0.2187x - 13.366
R² = 0.5952
0
2
4
6
8
10
12
14
70
80
90
100
110


Breton - Base Case Cooling Schedule
Peak Power
Super Peak Power
Power (kWh/day)
Max Daily Temp (°F)
y = 0.0342x + 3.4132
R² = 0.0489
y = 0.0437x + 2.1762
R² = 0.019
0
2
4
6
8
10
12
14
70
80
90
100
110


Breton
8/24/2005
9/18/2005
Temp
kW
0
20
40
60
80
100
0
2
4
6
8
10
12
14
8/16
8/23
8/30
9/6
9/13
9/20
Pre-Cooling Schedule 1
Tout max
Tout avg
Daily Total Energy
Peak Power
Super Peak Power
AC Peak Power
AC Super Peak Power



Breton - Data Captured (%)
Temp (degF)
200
180
160
140
120
100
80
60
40
20
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
8/16
8/23
8/30
9/6
9/13
9/20
9/9/2005
8/24/2005
9/18/2005
Pre-Cooling Schedule 1
Tout max
Ti1 % Data
Ti2 % Data
Tout % Data
P % Data
AC % Data

Annual Energy and Demand Summary

76F Cooling Setpoint, 71F Precooling Setpoint

	Annual kWh			Peak KW		
	Off-Peak	Peak	Super Peak	Off-Peak	Peak	Super Peak
Base	6691	1608	3291	5.92	5.82	6.16
6am-12pm	7532	1379	3108	5.88	5.72	6.15
6am-2pm	7569	1773	2890	5.86	5.74	6.15
8am-12pm	7383	1406	3132	5.91	5.77	6.16
8am-2pm	7425	1787	2920	5.91	5.83	6.16

	kWh Savings			Demand Savings (kW)		
	Total	Peak	Super Peak	Off-Peak	Peak	Super Peak
6am-12pm	-429	229	183	0.04	0.10	0.010
6am-2pm	-642	-165	401	0.06	0.08	**0.010**
8am-12pm	-331	202	159	0.01	0.05	0.00
8am-2pm	-542	-179	371	0.01	-0.01	0.00

78F Cooling Setpoint, 73F Precooling Setpoint

	Annual kWh			Peak KW		
	Off-Peak	Peak	Super Peak	Off-Peak	Peak	Super Peak
Base	6225	1445	3002	5.98	5.82	6.20
6am-12pm	7043	1212	2809	5.92	5.40	6.17
6am-2pm	7081	1660	2565	5.83	5.82	6.15
8am-12pm	6947	1231	2826	5.96	5.70	6.17
8am-2pm	6990	1668	2587	5.96	5.93	6.16

	kWh Savings			Demand Savings (kW)		
	Total	Peak	Super Peak	Off-Peak	Peak	Super Peak
6am-12pm	-392	233	193	0.06	0.42	0.03
6am-2pm	-634	-215	437	0.15	0.00	**0.05**
8am-12pm	-332	214	176	0.02	0.12	0.03
8am-2pm	-573	-223	415	0.02	-0.11	0.04

80F Cooling Setpoint, 75F Precooling Setpoint

	Annual kWh			Peak KW		
	Off-Peak	Peak	Super Peak	Off-Peak	Peak	Super Peak
Base	5829	1301	2732	5.83	5.48	6.17
6am-12pm	6592	1080	2543	5.59	4.84	6.17
6am-2pm	6630	1550	2288	5.57	5.92	6.02
8am-12pm	6532	1092	2555	5.71	5.13	6.17
8am-2pm	6575	1555	2303	5.62	5.97	6.11
	kWh Savings			Demand Savings (kW)		
	Total	Peak	Super Peak	Off-Peak	Peak	Super Peak
6am-12pm	-353	221	189	0.24	0.64	0.00
6am-2pm	-606	-249	444	0.26	-0.44	**0.15**
8am-12pm	-317	209	177	0.12	0.35	0.00
8am-2pm	-571	-254	429	0.21	-0.49	0.06

Peak Day Summary - Aug. 20th (103F)

76F Cooling Setpoint, 71F Precooling Setpoint

	Peak Day KW		
	Off-Peak	Peak	Super Peak
Base	4.73	5.36	5.95
6am-12pm	4.60	5.26	5.88
6am-2pm	4.60	5.27	5.88
8am-12pm	4.66	5.34	5.93
8am-2pm	4.66	5.34	5.93

	Demand Savings (kW)		
	Total	Peak	Super Peak
6am-12pm	0.13	0.10	**0.07**
6am-2pm	0.13	0.09	**0.07**
8am-12pm	0.07	0.02	0.02
8am-2pm	0.07	0.02	0.02

Annual Energy Cost Summary

Time Of Use Rate

76F Cooling Setpoint,

71F Precooling Setpoint

	Utility Cost	Savings
Base	$1,442	
6am-12pm	$1,442	$0
6am-2pm	$1,453	-$11
8am-12pm	$1,438	$4
8am-2pm	$1,449	-$7

78F Cooling Setpoint, 73F Precooling Setpoint

	Peak Day KW		
	Off-Peak	Peak	Super Peak
Base	4.63	5.48	6.03
6am-12pm	4.69	5.25	6.00
6am-2pm	4.68	5.34	5.99
8am-12pm	4.74	5.46	6.00
8am-2pm	4.73	5.41	6.00
	Demand Savings (kW)		
	Total	Peak	Super Peak
6am-12pm	-0.06	0.23	0.03
6am-2pm	-0.05	0.14	**0.04**
8am-12pm	-0.11	0.02	0.03
8am-2pm	-0.10	0.07	0.03

78F Cooling Setpoint,

73F Precooling Setpoint

	Utility Cost	Savings
Base	$1,322	
6am-12pm	$1,317	$5
6am-2pm	$1,331	-$8
8am-12pm	$1,316	$7
8am-2pm	$1,329	-$7

80F Cooling Setpoint, 75F Precooling Setpoint

	Peak Day KW		
	Off-Peak	Peak	Super Peak
Base	4.27	5.37	6.07
6am-12pm	4.77	4.67	5.78
6am-2pm	4.77	5.42	5.64
8am-12pm	4.99	4.87	5.89
8am-2pm	4.91	5.47	5.75
	Demand Savings (kW)		
	Total	Peak	Super Peak
6am-12pm	-0.50	0.70	0.29
6am-2pm	-0.50	-0.05	**0.43**
8am-12pm	-0.72	0.50	0.18
8am-2pm	-0.64	-0.10	0.32

80F Cooling Setpoint,

75F Precooling Setpoint

	Utility Cost	Savings
Base	$1,215	
6am-12pm	$1,208	$7
6am-2pm	$1,222	-$7
8am-12pm	$1,207	$8
8am-2pm	$1,221	-$6

Annual Energy and Demand Summary

80F Cooling Setpoint, 71F Precooling Setpoint

	Annual kWh			Peak KW		
	Off-Peak	Peak	Super Peak	Off-Peak	Peak	Super Peak
Base	5829	1301	2732	5.83	5.48	6.17
6am-12pm	7281	989	2368	5.51	4.68	6.01
6am-2pm	7346	1665	2062	5.53	5.87	5.82
8am-12pm	7018	1034	2424	5.71	5.13	6.17
8am-2pm	7099	1682	2125	5.61	5.97	6.06

	kWh Savings			Demand Savings (kW)		
	Total	Peak	Super Peak	Off-Peak	Peak	Super Peak
6am-12pm	-776	312	364	0.32	0.80	0.16
6am-2pm	-1211	-364	670	0.30	-0.39	**0.35**
8am-12pm	-614	267	308	0.12	0.35	0.00
8am-2pm	-1044	-381	607	0.22	-0.49	0.11

Peak Day Summary - Aug. 20th (103F)

Base	4.27	5.37	6.07
6am-12pm	4.71	4.43	5.67
6am-2pm	4.7	5.36	5.5
8am-12pm	5.03	4.86	5.88
8am-2pm	5.01	5.47	5.73
	Demand Savings (kW)		
	Total	Peak	Super Peak
6am-12pm	-0.44	0.94	0.40
6am-2pm	-0.43	0.01	**0.57**
8am-12pm	-0.76	0.51	0.19
8am-2pm	-0.74	-0.10	0.34

Annual Energy Cost Summary

Time Of Use Rate

	Utility Cost	Savings
Base	$1,215	
6am-12pm	$1,215	-$1
6am-2pm	$1,249	-$34
8am-12pm	$1,212	$3
8am-2pm	$1,244	-$29

Conclusions

One of the focus points of the project was to use off the shelf retail or generally available products as much as possible. For the most part, we were successful with the exception of the My Energy system which we knew upfront we'd have to create.

A second focus area was overall system reliability. As mentioned above, x10 communication to the thermostats was an issue but was resolved overall with additional hardware and some custom logging software. When thermostats using current command and control protocols such as Universal Powerline Bus are available, these issues will be a thing of the past. UPB based thermostats are expected by the end of 2005.

Home Automation and overall platform stability was extremely high with only 1-2 system issues across all 3 systems over the course of the 3 months of setup, data logging, and testing. In one case, network communication issues but did not cause a loss of data logging or impact in home functionality.

Interest in My Energy, awareness, was very high and the project is on the verge of implementing a billing estimation system. This system would allow the home owner to proactively reduce their monthly bill via implementation of energy saving tips and techniques. We will soon validate our calculations and implement this system in all 3 prototype homes. My Energy usage needs to continue to gain significant participant "run time" and then survey individual impact and satisfaction.

The pre-cooling testing resulted in findings that were more positive and likely to provide positive results than, at least I, expected. Unfortunately, the project ran out of warm weather before we were able to implement a PC based dynamic pre-cooling system, which would have provided an even more efficiency.

Next steps / future opportunities

We are currently talking with other utilities whom may be interested in similar capabilities. Additionally, SMUD would like to continue the pre-cooling study next summer, having all systems (and possibly additional homes) ready to go before the warm weather hits and to run the study throughout the entire summer months. The possibility to include these and other Energy Management scenarios into the practical life pillar of the Digital Home is something else that should be considered. Additionally, other types of measurements could be added to the system including natural gas, which is expected to increase in cost by as much as 50 percent this year. Lastly, there is a growing worldwide interest in end load measurement capabilities.

Project Bill of Materials

Item	Each	Quantity	Sub Total	Notes
Intel processor based Media Center PC	$1,628.99	3	$4,886.97	High End
x10 Computer Interface	$37.99	3	$113.97	
x10 Thermostat	$250.00	8	$2,000.00	inside & outside (3 ea in two homes 2 ea in one home)
Automation Software	$400.00	3	$1,200.00	
Voice Modem / Interface	$99.00	3	$297.00	
Misc.	$50.00	3	$150.00	
		Total	$8,647.94	

Note: The Same or similar scenarios could be implemented at lower costs. Project goal was conceptual prototyping, not scaling for mass production / deployment.

Project Plan

Major Milestone	Owner	Goal	Date	Status	Notes
Project approved / funded via R&D council	Breton	4/21/05	4/21/05	Completed	
Hardware ordered & received	Breton	5/31/05	7/21/05	Completed	Availability and purchasing issues
Meter reading technology provided	Itron	5/31/05	7/12/05	Completed	
Storyboard	Breton	TBD		In Process	
SMUD project funded	SMUD	June 05	7/27/05	Completed	
Davis Energy Group contacted	SMUD	June 05	7/27/05	Completed	
Thermostats installed	Breton	7/29/05	7/29/05	Completed	
Control systems installed	Breton	7/29/05	7/29/05	Competed	
Data Gathering scripts setup & logging	Breton	7/29/05	7/29/05	Completed	
Meters installed	SMUD	July	8/16/05	Completed	
Meter reading & logging	Breton	July	8/16/05 8/19/05 8/20/05	Completed	
PreCooling VB framework created and delivered to Davis Energy Group	Breton	7/29/05	7/26/05	Completed	
PreCooling VB application finished	Davis Energy Group	TBD		Postponed	
Setup FTP host and script to store logging data /w Davis Energy Group access	Breton	7/29/05	7/28/05	Competed	
Homes moved to TOU Rate	SMUD	Aug	Oct	Completed	Eng
PreCooling trial start	All	09/15/05		Completed	Worse case – Goal

					to pull in to Aug
PreCooling trial end	All	09/30/05		Completed	
PreCooling Results Reported	Davis Energy Group	Oct		In Process	Looks more like Nov
Overall Project Documentation Completed	Breton	10/14/05	10/14/05	Completed	

References

SMUD (Sacramento Municipal Utility District)

http://smud.org/

Davis Energy Group (Energy Consultant)

http://www.davisenergy.com/

Smarthome (Manufacture and distributor of home automation products)

http://www.smarthome.com/

Simply Automated (Manufacture of UPB based devices)

http://simply-automated.com

Home Controls (Distributed of Simply Automated, & other automation products)

http://www.homecontrols.com

Home Automated Living (Creators of the HAL2000 Home Automation Software)

http://www.automatedliving.com

Residential Control Systems (Manufacture of HVAC control products)

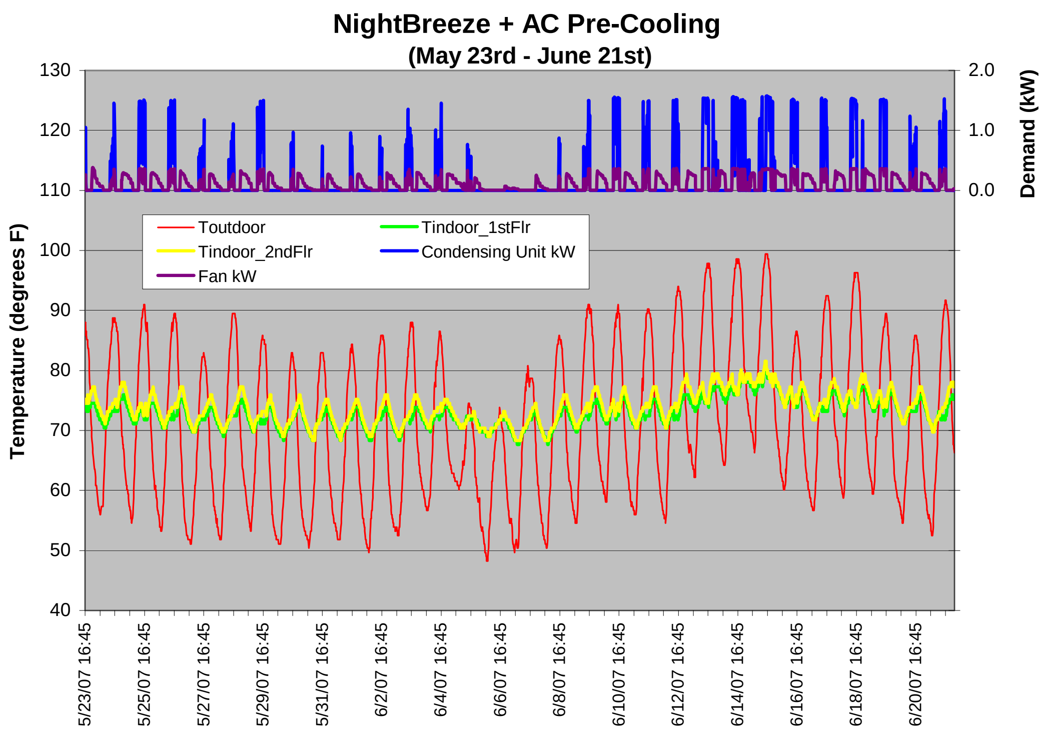
http://www.resconsys.com

Powerline Control Systems (Developers of the UPB Protocol)

http://pcslighting.com

Appendix C:
Field Monitoring Data

This appendix contains time series plots of the data collected during the 2007 summer. The data includes indoor and outdoor temperatures, air handler fan power, and condensing unit power. Data were collected in a variety of operating modes. Daily National Weather Service downtown Sacramento data is listed following the time series plots. The test mode periods are also listed on the daily summary.


NightBreeze + AC Pre-Cooling
(May 23rd - June 21st)
Temperature (degrees F)
Demand (kW)
Toutdoor
Tindoor_1stFlr
Tindoor_2ndFlr
Condensing Unit kW
Fan kW
5/23/07 16:45
5/25/07 16:45
5/27/07 16:45
5/29/07 16:45
5/31/07 16:45
6/2/07 16:45
6/4/07 16:45
6/6/07 16:45
6/8/07 16:45
6/10/07 16:45
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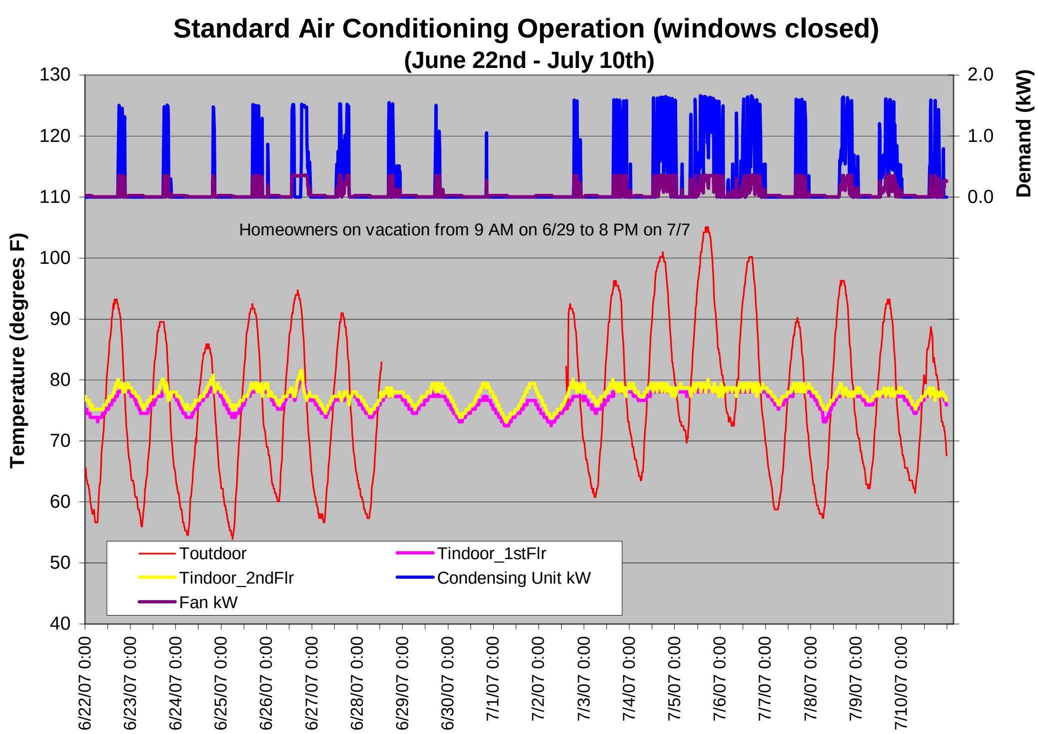
6/18/07 16:45
6/20/07 16:45


Standard Air Conditioning Operation (windows closed)
(June 22nd - July 10th)
Temperature (degrees F)
Demand (kW)
Homeowners on vacation from 9 AM on 6/29 to 8 PM on 7/7
Toutdoor
Tindoor_1stFlr
Tindoor_2ndFlr
Condensing Unit kW
Fan kW
6/22/07 0:00
6/23/07 0:00
6/24/07 0:00
6/25/07 0:00
6/26/07 0:00
6/27/07 0:00
6/28/07 0:00
6/29/07 0:00
6/30/07 0:00
7/1/07 0:00
7/2/07 0:00
7/3/07 0:00
7/4/07 0:00
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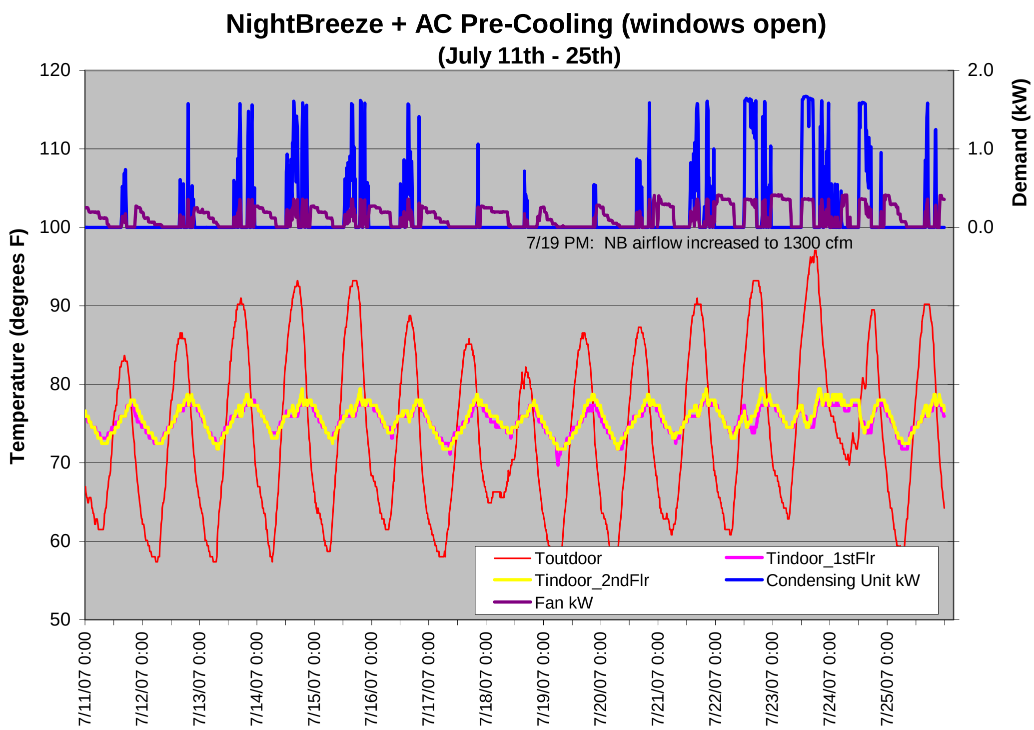
7/9/07 0:00
7/10/07 0:00


NightBreeze + AC Pre-Cooling (windows open)
(July 11th - 25th)
Temperature (degrees F)
Demand (kW)
120
110
100
90
80
70
60
50
2.0
1.0
0.0
7/19 PM: NB airflow increased to 1300 cfm
Toutdoor
Tindoor_1stFlr
Tindoor_2ndFlr
Condensing Unit kW
Fan kW
7/11/07 0:00
7/12/07 0:00
7/13/07 0:00
7/14/07 0:00
7/15/07 0:00
7/16/07 0:00
7/17/07 0:00
7/18/07 0:00
7/19/07 0:00
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7/22/07 0:00
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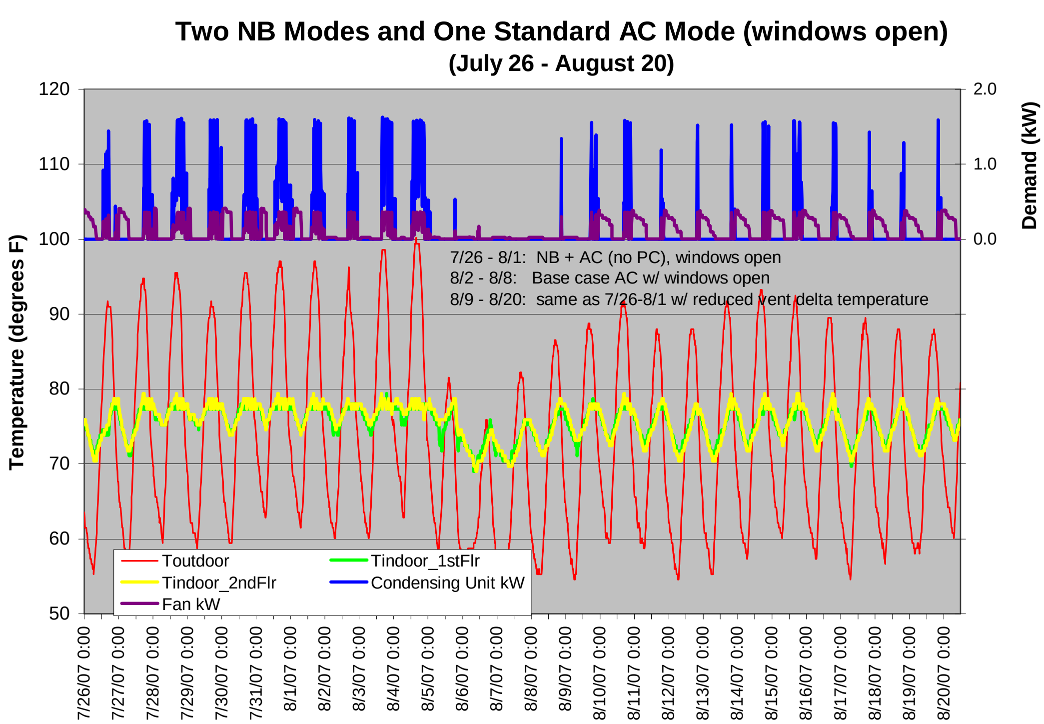
7/24/07 0:00
7/25/07 0:00


Two NB Modes and One Standard AC Mode (windows open)
(July 26 - August 20)
Temperature (degrees F)
Demand (kW)
120
110
100
90
80
70
60
50
2.0
1.0
0.0
7/26 - 8/1: NB + AC (no PC), windows open
8/2 - 8/8: Base case AC w/ windows open
8/9 - 8/20: same as 7/26-8/1 w/ reduced vent delta temperature
Toutdoor
Tindoor_1stFlr
Tindoor_2ndFlr
Condensing Unit kW
Fan kW
7/26/07 0:00
7/27/07 0:00
7/28/07 0:00
7/29/07 0:00
7/30/07 0:00
7/31/07 0:00
8/1/07 0:00
8/2/07 0:00
8/3/07 0:00
8/4/07 0:00
8/5/07 0:00
8/6/07 0:00
8/7/07 0:00
8/8/07 0:00
8/9/07 0:00
8/10/07 0:00
8/11/07 0:00
8/12/07 0:00
8/13/07 0:00
8/14/07 0:00
8/15/07 0:00
8/16/07 0:00
8/17/07 0:00
8/18/07 0:00
8/19/07 0:00
8/20/07 0:00

2007 Downtown Sacramento National Weather Service Data

		Maximum Toutdoor	Minimum Tindoor	Cooling Degree Days	Test Mode	Mode Comments
May	21	85	57	6		
	22	83	59	6		
	23	87	62	10	Test 1	NB + ACPC, 78F setpoint, 68F NBLL setting,
	24	90	59	10		PC 12-5 PM, 5F VentDeltaTemp, 5F PC offset,
	25	90	59	10		1700 (vs 2200 MaxCFM) VentCfm
	26	89	55	7		Windows Closed
	27	81	54	3		
	28	92	53	8		
	29	84	53	4		
	30	79	53	1		
	31	81	52	2		
June	1	82	53	3		
	2	85	53	4		
	3	88	53	6		
	4	86	58	7		
	5	77	59	3		
	6	74	51	0		
	7	81	53	2		
	8	86	53	5		
	9	91	57	9		
	10	89	62	11		
	11	91	58	10		
	12	96	59	13		
	13	100	64	17		
	14	102	68	20		
	15	102	66	19		Freus Problems
	16	83	59	6		
	17	94	58	11		
	18	99	63	16		
	19	87	61	9		
	20	85	57	6		
	21	93	55	9		
	22	93	60	12	Test 2	Base Case AC (78F) with Windows Closed
	23	90	60	10		
	24	87	57	7		
	25	94	57	11		
	26	95	63	14		
	27	90	59	10		
	28	88	59	9		
	29	86	61	9	Begin Vacation- house unoccupied	
	0	86	58	7		
July	1	89	57	8		
	2	94	59	12		
	3	99	64	17		
	4	105	67	21		
	5	108	71	25		
	6	99	62	16		
	7	87	58	8	End Vacation- house occupied	
	8	97	59	13		
	9	94	62	13		
	10	86	60	8		
	11	82	62	7	Test 3	NB + ACPC (as in Test 1) with Windows Open
	12	86	58	7		
	13	93	59	11		
	14	94	61	13		
	15	96	61	14		
	16	87	62	10		
	17	87	59	8		
	18	83	62	8		
	19	88	59	9	Set VentFanCFM to 1300 (MAXCFM also 1300)	
	20	89	60	10		
	21	93	64	14		
	22	97	64	16		
	23	98	66	17		
	24	94	64	14		
	25	90	60	10		
	26	93	57	10	Test 4	NB, No PC, 1300 CFM, Windows Open
	27	97	57	12		
	28	97	61	14		
	29	94	59	12		

	30	99	61	15		
	31	99	66	18		
August	1	99	60	15		
	2	94	61	13	Test 5	Base Case AC (78F) with Windows Open
	3	101	61	16		
	4	104	65	20		
	5	76	59	3		
	6	74	59	2		
	7	82	56	4		
	8	88	57	8		
	9	91	58	10	Test 6	NB, No PC, 1300 CFM, Windows Open, 3F VentDeltaTemp
	10	94	62	13		
	11	88	60	9		
	12	90	58	9		
	13	94	59	12		
	14	95	59	12		
	15	94	62	13		
	16	92	61	12		
	17	92	57	10		
	18	89	60	10		
	19	89	59	9		
	20	95	68	17		
	21	100	66	18	Test 7	NB + ACPC, 78F setpoint, 68F NBLL setting, PC 12-5PM,
	22	101	66	19		3F VentDeltaTemp, 5F PC offset, 1300 VentCfm
	23	101	66	19		Windows Closed, New NB prgm to reduce rampdown
	24	94	62	13		
	25	90	61	11		
	26	91	59	10		
	27	94	59	12		
	28	100	63	17		
	29	105	71	23	raised Super Peak setpoint to 79F for this day	
	30	104	74	24		
	31	101	76	24		
September	1	102	71	22		
	2	101	65	18		
	3	98	65	17		
	4	87	63	10		
	5	90	62	11		
	6	96	63	15		
	7	83	61	7		
	8	92	58	10		
	9	85	57	6		
	10	87	59	8		
	11	89	59	9		
	12	78	59	4		
	13	78	59	4		
	14	81	58	5		
	15	78	58	3		
	16	81	56	4		
	17	83	59	6		
	18	83	60	7		
	19	74	53	0		
	20	70	52	0		
	21	80	52	1		
	22	64	59	0		
	23	74	59	2		
	24	81	52	2		
	25	86	51	4		
	26	89	55	7		
	27	90	55	8		
	28	69	53	0		
	29	74	47	0		
	30	80	48	0		